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TECHNICAL REPORT

Review of Injuries from Terrorist Bombings and Earthquakes

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14. ABSTRACT

Terrorist bombings and earthquakes provide valuable insight on the types of injuries that may occur in an improvised nuclear device (IND) scenario. Review of blast events provided information on injuries from overpressure, tumbling, debris, burn, and crush injuries. Data from eighteen case studies based on 432 bombings revealed 16,699 different injuries among 6,554 casualties. Injury types included wounds, fractures, and burns. Body areas typically involved the head and neck, extremities, and soft tissues. Glass shattering was a common source of injury. Eight earthquake case studies were reviewed with 6,775 injuries reported for 4,526 casualties. The most common types of wound and body regions include fractures, crush, and contusions and extremities, back, and hip. Earthquake injuries primarily originate from building collapse causing persons to be hit, trapped, or crushed by building parts. The report details the spectrum and quantity of injuries resulting from blast and earthquakes, thereby providing valuable information for response planning for an IND. Knowledge concerning anticipated injury types provide data for casualty estimation and help inform medical response planning and resource requirements.

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Unit Conversion Table

U.S. customary units to and from international units of measurement*

U.S. Customary Units	Multiply by → / ← Divide by†		International Units
Length/Area/Volume			
inch (in)	2.54	$\times 10^{-2}$	meter (m)
foot (ft)	3.048	$\times 10^{-1}$	meter (m)
yard (yd)	9.144	$\times 10^{-1}$	meter (m)
mile (mi, international)	1.609 344	$\times 10^{3}$	meter (m)
mile (nmi, nautical, U.S.)	1.852	$\times 10^{3}$	meter (m)
barn (b)	1	$\times 10^{-28}$	square meter (m^2)
gallon (gal, U.S. liquid)	3.785 412	$\times 10^{-3}$	cubic meter (m^3)
cubic foot (ft^3)	2.831 685	$\times 10^{-2}$	cubic meter (m^3)
Mass/Density			
pound (lb)	4.535 924	$\times 10^{-1}$	kilogram (kg)
unified atomic mass unit (amu)	1.660 539	$\times 10^{-27}$	kilogram (kg)
pound-mass per cubic foot (lb ft^{-3})	1.601 846	$\times 10^{1}$	kilogram per cubic meter (kg m^{-3})
pound-force (lbf avoirdupois)	4.448 222		newton (N)
Energy/Work/Power			
electron volt (eV)	1.602 177	$\times 10^{-19}$	joule (J)
erg	1	$\times 10^{-7}$	joule (J)
kiloton (kt) (TNT equivalent)	4.184	$\times 10^{12}$	joule (J)
British thermal unit (Btu) (thermochemical)	1.054 350	$\times 10^{3}$	joule (J)
foot-pound-force (ft lbf)	1.355 818		joule (J)
calorie (cal) (thermochemical)	4.184		joule (J)
Pressure			
atmosphere (atm)	1.013 250	$\times 10^{5}$	pascal (Pa)
pound force per square inch (psi)	6.984 757	$\times 10^{3}$	pascal (Pa)
Temperature			
degree Fahrenheit (^oF)	$[T(^oF) - 32]/1.8$		degree Celsius (^oC)
degree Fahrenheit (^oF)	$[T(^oF) + 459.67]/1.8$		kelvin (K)
Radiation			
curie (Ci) [activity of radionuclides]	3.7	$\times 10^{10}$	per second (s^{-1}) [becquerel (Bq)]
roentgen (R) [air exposure]	2.579 760	$\times 10^{-4}$	coulomb per kilogram (C kg^{-1})
rad [absorbed dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [gray (Gy)]
rem [equivalent and effective dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [sievert (Sv)]

*Specific details regarding the implementation of SI units may be viewed at http://www.bipm.org/en/si/.

†Multiply the U.S. customary unit by the factor to get the international unit. Divide the international unit by the factor to get the U.S. customary unit.

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Executive Summary

Historical data from Hiroshima and Nagasaki indicate that a wide range of thermal, blast, radiation, and combined injuries can be anticipated (Geiger 1964; Goans 2009). However, the types of buildings found in Hiroshima and Nagasaki at the time of the bombings are very different from those found in metropolitan areas today. The review of case studies on terrorist bombings and earthquakes can provide valuable insight to the types of injuries that are likely to occur after an improvised nuclear device (IND) detonation. Typical blast injuries from bombings and earthquakes result from the effects of overpressure, tumbling, debris, burn, and crush. These effects are relevant to the environment expected for an IND detonation. Therefore, blast-related injuries from terrorist bombings and injuries occurring after earthquakes were reviewed according to case study data available in the open literature.

Data were collected and analyzed for eighteen blast case studies. This represents 432 bombings which collectively report 16,699 different injuries in 6,554 casualties (an average of 2.55 injuries per person). Distinct physical injury types included open wounds, fractures, and burns. More than half of the blast injuries resulted from tumbling or displacement of the victim (tertiary). Shattered glass was also a common source of injury (secondary) while flash burns were the primary type of burn encountered (quaternary). While the primary blast effects accounted for almost 12% of the total injuries they are not emphasized in the this review because in an IND scenario an individual exposed to the primary effects would also likely be exposed to radiation and thermal effects that would not be survivable.

Data were collected and analyzed for eight earthquake case studies to further investigate the effects of collapsing buildings. These case studies were limited to earthquakes that registered at least 7.0 on the Richter scale and collectively reported 6,775 different injuries in 4,526 casualties (an average of 1.50 injuries per person). Fractures and other crush injuries were the most common types of injuries encountered. Earthquake injuries primarily originate from collapsing buildings causing persons to be hit, trapped, or crushed by building debris.

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1.0 Introduction

As part of its mission to safeguard against weapons of mass destruction (WMD), the Defense Threat Reduction Agency (DTRA) supports the development of capabilities to reduce, eliminate and counter WMD threats and mitigate their effects. Applied Research Associates (ARA) was tasked by DTRA to support this mission by developing a model that predicts health effects from WMD scenarios, such as the detonation of an improvised nuclear device (IND). The aim of our work is to enhance our understanding of the potential impact of an IND by improving casualty estimation capabilities, predict the time course of injuries and their outcomes, and understand their impact on medical resource requirements. ARA has a history of using advanced modeling techniques for IND scenarios to estimate the transport of radiation, thermal fluence, and the blast wave in the urban environment (Weber and Kramer 2010; Weber and Millage 2011; Weber and Millage 2012). However, there is still a need to extrapolate urban environment calculations to the number of injuries anticipated, the probability of multiple (combined) injuries, their clinical manifestations, and their impact on resource requirements (Stricklin et al. 2010; Wentz 2015).

One gap of information currently identified in our efforts is an understanding of the numbers and spectrum of injuries that will occur after an IND event in a modern urban setting. Historical data from Hiroshima and Nagasaki indicate that a wide range of thermal, blast, radiation, and combined injuries can be anticipated (Geiger 1964; Goans 2009). However, the types of buildings found in Hiroshima and Nagasaki at the time of the bombings are very different from those found in metropolitan areas today.

The focus of this work was to improve our understanding of the types and numbers of injuries that result in the urban setting by studying events that have comparable effects. Our aim was to gain insight into what type of injuries occur within urban structures when they are devastated either by blast or earthquake. Blast scenarios such as terrorist bombings result in overpressure, thermal energy, glass shattering, flying debris, and forces that can result in tumbling or in some cases building collapse. Rarely does a bombing result in a complete building collapse, but some of the studies reviewed exhibit partial building collapse or structural damage (such as Oklahoma City Bombing). When evaluating structural response to blast, there is a difference in the duration of the overpressure wave between the conventional bombings (all case studies) and an IND explosion. The forces of an IND explosion typically involve a longer duration overpressure wave that enables entire buildings to be engulfed before it passes and creates drag type forces (Needham 2010). These forces will act on the buildings resulting in a "mass distortion" of the buildings, similar to what is seen in earthquake situations. Therefore, the specific aim of this study was to collect data on the types of injuries that have occurred after terrorist bombings and earthquakes with particular emphasis on injuries resulting from urban structures.

Table 1-1 describes the characteristics of four main blast injury categories: primary, secondary, tertiary, and quaternary (Stuhmiller 2008). Primary blast injury is the result of the overpressure wave that can travel through air, water, or other media and subsequently impact internal parts of the body. Organs and tissues that are normally affected by overpressure are the ears, gas-filled structures (primarily, the lungs and gastrointestinal (GI) tract), and soft tissues. Common types of primary blast injuries are "blast lung" and abdominal, ear, and eye injuries. Secondary blast

injury occurs from flying debris and bomb fragments which can affect any part of the body. The types of injuries associated with secondary blast injury include lacerations and penetrating injuries. Tertiary blast injury occurs when someone is propelled by the blast wave causing displacement and tumbling with impact against stationary objects. Such impact can affect any part of the body, and will often result in fractures. Quaternary blast injury includes any other injury not caused from blast itself, such as building collapse or fire. Quaternary injuries include burns, respiratory damage due to smoke, dust, or fumes, and crush injuries. Many incidents result in multiple types of blast injuries (Ramasamy 2011; Slater and Trunkey 1997; Martí et al. 2006).

Table 1-1 Blast injury categories, characteristics, body area affected, and types of injuries (Stuhmiller 2008)

Category	Characteristics	Body Area Affected	Example Types of Injuries
Primary	Results from impact of overpressure wave (shock wave) with the body.	Air filled structures: Lungs Ears GI tract Soft tissue	Tympanic membrane rupture, Middle ear damage, Abdominal hemorrhage, Globe (eye) rupture, Pulmonary contusion
Secondary	Results from flying debris and bomb fragments	Any	Penetrating ballistic injuries, Blunt injuries, Lacerations
Tertiary	Results from tumbling/displacement of a person by blast forces and subsequent impact with a fixed object	Any	Fractures, Closed and open brain injuries, Traumatic amputations, Blunt trauma
Quaternary	Injuries not associated with blast wave or pressure effects. Including complications of existing conditions	Any	Burns (flash or partial), Asphyxia, Crush injuries, Inhalation injuries, Asthma, angina, hyperglycemia, hypertension, etc.

2.0 Methods

A literature search was performed focusing on terrorist bombings that affected multiple people and produced a blast wave. A second search was performed focusing on earthquakes with a magnitude of at least 7.0 on the Richter scale and involved building collapse. From these reviews, 34 literature references contained relevant information on specific types of injury for our analysis.

2.1 Bombings

The bombing incident case studies included in our data collection were those for which the bombing; 1) occurred in urban areas large enough to involve multiple people, 2) produced a blast wave that resulted in individuals being physically moved, and 3) a description of the injuries were provided. Since the purpose of this work was to gain information on types and numbers of injuries, only case studies that provided a description of injuries were included. A total of 18 case studies based on a total of 432 different terrorist bombings were reviewed in this work. While many of the case studies described injuries consistently, there were some instances where similar injuries have been described differently. Table A-27 and Table A-28 in the Appendix detail how the blast injuries described in each study were assigned to our injury type and injury categories.

Primary blast injuries involving damage from overpressure were not emphasized in this study since the primary goal was to provide data to correlate with survivable injuries from an IND. In an IND detonation, persons close enough to ground zero to receive overpressure injuries will most likely sustain a combination of injuries from blast, radiation, and thermal effects that are not survivable. Table 2-1 lists primary blast injuries not emphasized in this review. To determine which injuries could be primary blast injuries, any of the injury types listed in Table 2-1 were assumed to be caused by the overpressure wave unless stated otherwise in the literature reference. For completeness, such injuries are tabulated separately for each case study but are not compiled for analysis.

Table 2-1 Compilation of primary blast injuries that are not emphasized in our analysis

Body Area	Injury Type
Lung	(Blast) Lung Injury, Pulmonary Contusion
Ear	Hearing Loss, Eardrum Rupture, Tympanic Membrane Rupture
Eye	(Globe) Eye Injury
Abdomen	Blast Abdomen Injury, Perforated Viscera

2.2 Earthquakes

In order to gain additional information on the types of injuries resulting from building collapse, earthquake case studies can be evaluated (Casagrande et al. 2011). Data from earthquakes provide insight on injuries resulting from falling debris and crush. The selection criteria for earthquake incidents were those that detailed earthquake-related injuries and involved building

collapse. The data collected from these sources depict specific case studies rather than the entire population affected by the specific earthquake, and therefore, represents only a subset of all persons injured in the event. The injuries that commonly result from earthquakes are from victims being crushed or pinned so rather than listing all of these injuries as "crush" injuries the specific type of injury (i.e. fracture, soft tissue injury, etc.) was listed.

2.3 Data Reported

Data on the number of people injured and the types of injuries obtained were collected from each of the case studies. The data were grouped together for some injury types (i.e. fractures, amputations, superficial or minor wounds, etc.) when applicable in Sections 3.0 and 5.0. The unconsolidated data are listed in the Appendix. These data are valuable in understanding the probability of different injury types and the percent values are useful in comparing different injury patterns in different scenarios and incident types. The percent of each specific type of injury among all casualties was obtained as follows:

$$\text{Percent of specific injuries } \textit{among all injuries} = \frac{\text{\# of injuries for a specific injury type}}{\text{total number of injuries in the data}} * 100\%$$

$$\text{Percent of specific injuries } \textit{among all casualties} = \frac{\text{\# of injuries for a specific injury type}}{\text{total \# of casualties}} * 100\%$$

The data were compiled to obtain average number of injuries per person for the collective incidents and which type of injuries were the most common. These data could be used in the future to develop probability of injury functions for an IND scenario. Details regarding the insults and the environment if they were reported were also collected such as the explosive yield of the bombs or the magnitude of the earthquake, building damage, resulting fires, etc. Finally, the data for blast events and earthquakes are compiled in Sections 4.0 and 6.0, respectively, and then discussed in Section 7.0.

3.0 Blast Results

The data collected from case studies involving eighteen blast-type terrorist events are reviewed and analyzed in Sections 3.1 to 3.18.

3.1 Belfast, Northern Ireland, 1969-1972

Between August 1969 and June 1972, a total of 110 bombings of varying yield occurred in Belfast, Northern Ireland. These attacks resulted in 1,582 casualties and 117 deaths (Frykberg and Tepas 1988; Hadden et al. 1978). Of the total casualties, the records of 1,532 patients taken to the Accident and Emergency Department of Royal Victoria Hospital were recovered and examined. These records (detailed in Table 3-1) show that a total of 2,599 injuries were sustained by the 1,532 patients, but only 250 patients' injuries were severe enough to admit them into the hospital (1.70 injuries per person) (Hadden et al. 1978).

Table 3-1 Types of injuries sustained in the Belfast bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**96**	--
Eye Injury	12	--
Perforated Tympanic Membrane	15	--
Hearing Loss	67	--
Blast Lung	2	--
Lacerations/Cuts	863	34.48%
Abrasions	359	14.34%
Contusions/Bruises	244	9.75%
Fractures/Dislocations	105	4.19%
Soft Tissue Injuries	38	1.52%
Concussions	34	1.36%
Neurovascular Injury	8	0.32%
Amputations	20	0.80%
Chest Injury	10	0.40%
Burns	50	2.00%
Psychiatric Trauma	772	30.84%
Total Non-Primary Injuries	**2,503**	

96 of the reported injuries were assumed to be caused by primary blast effects and the remaining 2,503 were caused by secondary, tertiary, or collateral effects. The most common physical injuries among the non-primary injuries were lacerations or cuts (863 injuries, 34%), minor abrasions (359 injuries, 14%), and contusions or bruises (244 injuries, 10%). More than half of the patients examined also reportedly suffered from psychiatric trauma. It should be noted that this study did not include patients under the age of 14 because the type of clothing worn by the age group was thought to be different than adults (Hadden et al. 1978).

3.2 Old Bailey, London, England, 1973

On February 6, 1973 a car bomb equivalent to 80 kg of TNT exploded at 2:50 pm at The Old Bailey in London, resulting in 160 casualties (Frykberg and Tepas 1988; Caro and Irving 1973). All of the casualties were taken to the hospital for treatment but only 19 were admitted in the end. The records of 154 of the patients examined were available for review and all of the injuries are listed in Table 3-2 (Caro and Irving 1973). The reported 151 injuries result in just less than one injury per person on average (0.98 injuries per person).

Table 3-2 Types of injuries sustained in the Old Bailey bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**0**	--
Lacerations/Cuts	55	36.42%
Abrasions	59	39.07%
Superficial/Minor Injuries or Wounds	24	15.89%
Neurovascular Injury	3	1.99%
Fractures	3	1.99%
Psychiatric Trauma	7	4.64%
Total Non-Primary Injuries	**151**	

None of the reported injuries could be directly attributed to primary blast injuries; therefore, all 151 injuries were caused by secondary, tertiary, or collateral effects. The most common physical injuries were abrasions (59 injuries, 39%) and lacerations or cuts (55 injuries, 36%). These injuries show that most patients were injured by flying debris (glass and metal) and not from displacement by the force of the blast itself (Tucker and Lettin 1975). A few of the injuries reported were related to psychiatric traumas including loss of consciousness and emotional shock (7 injuries, 5%).

3.3 Tower of London, London, England, 1974

On July 17, 1974 the Tower of London Museum in England was attacked with a bomb equivalent to 5 kg of TNT (Arnold et al. 2004; Tucker and Lettin 1975). The explosion took place in a room full of armor with the bomb placed next to a wooden gun carriage and an 18th century bronze cannon. The attack resulted in 37 casualties and 1 death as a result of severe brain damage. The records indicate that only 19 victims were admitted to the hospital with a total of 89 injuries (4.68 injuries per person) that are listed in Table 3-3.

Table 3-3 Types of injuries sustained in the Tower of London bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**30**	--
Pulmonary Contusion	2	--
Ear Injury	22	--
Abdominal Injury	2	--
Eye Damage	4	--
Soft Tissue Injuries	17	28.81%
Fractures	24	40.68%
Frontal Lobe and Brain Stem Damage	1	1.69%

Concussions	1	1.69%
Burns	10	16.95%
Open Joint Injuries	2	3.39%
Psychiatric Trauma	4	6.78%
Total Non-Primary Injuries	**59**	

We determined that 30 of the 89 injuries were causes by primary blast effects. The most common non-primary injuries were fractures (24 injuries, 41%) and various soft tissue injuries (17 injuries, 29%). The report also indicated that 10 of the 19 victims (53%) suffered from flash burns to areas of uncovered skin. Only 4 patients complained of psychiatric trauma and all symptoms improved with reassurance and tranquilizers (Tucker and Letting 1975).

3.4 Horse and Groom/Seven Stars Public House, Guildford, England, 1974

On October 5, 1974, two public houses in Guildford, England were attacked using bombs equivalent to 5 kg of TNT leading to 69 casualties and 5 deaths (Arnold et al. 2004). The first bomb exploded at the Horse and Groom Public House where the majority of the casualties and all of the deaths occurred. The second bombing occurred at the Seven Stars Public House, but significantly less casualties occurred (7) because rumors had spread of the threat of a second bomb and patrons were evacuating when the bomb was detonated (Hill 1979). The records indicate that only 24 of the 69 casualties were admitted to the hospital with a total of 42 injuries (1.75 injuries per person) which are listed in Table 3-4.

Table 3-4 Types of injuries sustained in the Horse and Groom and Seven Stars Public Houses bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**14**	--
Blast Lung	2	--
Eye Damage	3	--
Eardrum Rupture	9	--
Soft Tissue Injuries	11	39.29%
Burns	10	35.71%
Fractures	7	25.00%
Total Non-Primary Injuries	**28**	

We determined that 14 of the 42 injuries, which included eardrum rupture, eye damage, and blast lung damage, resulted from primary blast effects. The remaining injuries consisted of soft tissue injures (11 injuries, 39%), burns (10 injuries, 36%), and fractures (7 injuries 25%). It should be noted that soft tissue injuries included bruises, lacerations, and abrasions (Cooper et al. 1983).

3.5 Tavern in the Town/Mulberry Bush Public House, Birmingham, England, 1974

On November 21, 1974, two public houses in Birmingham, England were attacked using bombs equivalent to 5 kg of TNT leading to 119 casualties and 21 deaths (Arnold et al. 2004). One bomb exploded at the Tavern in the Town, an underground bar, which resulted in 89 casualties and 11 deaths. The second bombing occurred at the Mulberry Bush Public House and resulted in 30 casualties and 10 deaths (Hill 1979). The records indicate that only 42 of the 82 casualties

treated at Birmingham General Hospital were admitted to the hospital with a total of 84 injuries (2.00 injuries per person) that are detailed in Table 3-5.

Table 3-5 Types of injuries sustained in the Tavern in the Town and Mulberry Bush Public House bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**26**	--
Blast Lung	3	--
Eye Damage	6	--
Eardrum Rupture	17	--
Soft Tissue Injuries	22	37.93%
Burns	23	39.66%
Fractures	13	22.41%
Total Non-Primary Injuries	**58**	

It was determined that 26 of the 84 injuries, which included eardrum rupture, eye damage, and blast lung damage, resulted from primary blast effects. The remaining injuries consisted of soft tissue injures (22 injuries, 38%), burns (23 injuries, 40%), and fractures (13 injuries 22%). It should be noted that soft tissue injuries included bruises, lacerations, and abrasions (Cooper et al. 1983).

3.6 Craigavon, Northern Ireland, 1972-1980

Between September 1972 and December 1980, 142 of 350 victims were admitted to Craigavon Area Hospital in Northern Ireland as a result of 77 bombings (Pyper and Graham 1983). The detailed information of 339 bomb victims was examined because 11 victims were either dead on arrival, transferred, or records were insufficient. The majority of the blasts were small in size and injuries with 64 of the 77 bombings had 5 or fewer victims and only 3 incidents had more than 20 victims (Pyper and Graham 1983). Table 3-6 details 740 injuries in all for the 339 victims (2.18 injuries per person).

Table 3-6 Types of injuries sustained in the Northern Ireland bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**93**	--
Ear Injury	93	--
Superficial/Minor Injuries or Wounds	188	29.06%
Abrasions	199	30.76%
Burn	6	0.93%
Fractures	127	19.63%
Neurovascular Injury	4	0.62%
Amputations	12	1.85%
Penetrating Abdomen Injury	8	1.24%
Penetrating Chest Injury	4	0.62%
Head Injury	13	2.01%
Perforating Eye Injury	16	2.47%
Psychiatric Trauma	70	10.82%
Total Non-Primary Injuries	**647**	

All 93 of the ear injuries were determined to be caused by primary blast effects. The remaining 577 injuries were caused by secondary, tertiary, and collateral effects. The most common non-primary injuries were abrasions (199 injuries, 31%), superficial or minor injuries and wounds (188 injuries, 29%), and fractures (127 injuries, 20%). Of the 339 victims, 70 patients were reported to be suffering from psychiatric trauma (21%). There are five patients who died while in the hospital due to head injuries. These fatalities are assumed to be included in the data; however, this is not explicitly stated by the authors (Pyper and Graham 1983).

3.7 Bologna, Italy, 1980

In August 1980 a terrorist attack caused 291 casualties at the central railway station in Bologna, Italy. 73 of the injured persons died at the scene with an additional 11 succumbing to their wounds within two weeks of the bombing. Of the 218 casualties that survived the initial blast, 181 were admitted to the hospital, but only 107 of those admitted have detailed medical records available (Brismar and Bergenwald 1982). The 107 recorded victims had a total of 250 injuries (2.34 injuries per person) which are detailed in Table 3-7.

Table 3-7 Types of injuries sustained in the Bologna, Italy bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**33**	--
Abdominal Injury	7	--
Lung Contusion	4	--
Ear Injury	15	--
Eye Injury	7	--
Fractures	65	29.95%
Brain Contusion	6	2.76%
Concussions	27	12.44%
Chest Wall Injury	11	5.07%
Thoracic Injury	4	1.84%
Subcutaneous Emphysema	1	0.46%
Amputations	3	1.38%
Superficial/Minor Injuries or Wounds	57	26.27%
Lacerations/Cuts	15	6.91%
Burns	28	12.90%
Total Non-Primary Injuries	**217**	

A total of 33 injuries were determined to be caused by primary blast effects. Of the remaining 217 injuries, the most common occurring injuries were fractures (65 injuries, 30%) and superficial or minor injuries and wounds (57 injuries, 26%). No fires were reported as a result of the explosion, but a total of 28 burns were reported (13%). The burns were assumed to be caused by radiant heat from the explosion (Brismar and Bergenwald 1982).

3.8 Paris, France, 1985

Between December 7, 1985 and September 17, 1986 a total of 14 terrorist bombings were attempted, three of which failed, causing 268 casualties with 13 immediate deaths. 40 of the casualties were treated onsite and released while the remaining 205 were admitted to the hospital

(Rignault and Deligny 1989). The records indicate that the hospitalized victims had 461 total injuries (2.25 injuries per person) and are shown in Table 3-8.

Table 3-8 Types of injuries sustained in the Paris, France bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**81**	--
Ear Blast Lesion	39	--
Perforated Eardrum	27	--
Lung Blast Injury	6	--
Pulmonary Contusion	1	--
Abdominal Injury	8	--
Lacerations/Cuts	139	36.58%
Burns	100	26.32%
Other Skin Lesions	56	14.74%
Fractures	57	15.00%
Thoracic Injury	1	0.26%
Pneumomediastinum	1	0.26%
Eye Lesions	12	3.16%
Amputations	6	1.58%
Head Trauma	8	2.11%
Total Non-Primary Injuries	**380**	

A total of 81 injuries were determined to be caused by primary blast injuries including 39 ear blast lesions, 27 perforated eardrums, and 6 blast lung injuries. Of the remaining 380 non-primary injuries, the most common injuries were lacerations or cuts (139 injuries, 37%), burns (100 injuries, 26%), and fractures (57 injuries, 15%).

3.9 LaBelle Disco Club, Berlin, Germany, 1986

On April 5, 1986 a single bomb equivalent to 5 kg of TNT was detonated in the LaBelle Disco in Berlin, Germany. It was estimated that as many as 300 people were present at the time of the terrorist attack but only 261 casualties including 3 deaths were reported. The records of 80 American patients that were admitted to the hospital with a total of 105 injuries (1.31 injuries per person) are detailed in Table 3-9 (Boehm and James 1988).

Table 3-9 Types of injuries sustained in the LaBelle Disco bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**43**	--
Eye Injury	1	--
Perforated Tympanic Membrane	42	--
Burns	16	25.81%
Abrasions	12	19.35%
Superficial/Minor Injuries or Wounds	12	19.35%
Severe Multiple Trauma	3	4.84%
Orthopedic Related Injury	8	12.90%
Lacerations/Cuts	11	17.74%
Total Non-Primary Injuries	**62**	

The primary blast injuries included 42 perforated tympanic membranes and one unspecified eye injury for a total of 43 injuries. For the remaining non-primary blast injuries, the most common injuries were burn (16 injuries 26%) followed by abrasions and superficial or minor injuries or wounds (Each with 12 injuries, 19%). It should be noted that this data only included the 80 Americans that were injured and no other nationalities were described (Boehm and James 1988).

3.10 Jerusalem, Israel, 1988

In 1988, a bomb equivalent to 6 kg of TNT was detonated under a seat of a city bus in Jerusalem, Israel. Of the 58 passengers on the bus 3 were killed and 29 of the remaining 55 casualties were admitted to the hospital. The records of the 29 patients admitted to the hospital are detailed in Table 3-10 and show a total of 95 injuries (3.28 injuries per person) (Katz et al. 1989)

Table 3-10 Types of injuries sustained in the Jerusalem, Israel bombing in 1988

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**44**	--
Perforated Eardrum	22	--
Blast Lung	11	--
Abdominal Injury	4	--
Perforated Ileum	1	--
Perforated Colon	1	--
Eye Injury	5	--
Peritoneal-Signs	2	3.92%
Head Trauma	4	7.84%
Flail Chest	3	5.88%
Thoracic Injury	4	7.84%
Myocardial Contusion	2	3.92%
Amputations	1	1.96%
Fractures	10	19.61%
Burns	5	9.80%
Lacerations/Cuts	20	39.22%
Total Non-Primary Injuries	**51**	

A total of 44 of the 95 injuries were attributed to the primary blast effects of which the most common was perforated eardrums. Of the remaining non-primary injuries, the most commonly occurring injuries were lacerations or cuts (20 injuries, 39%) and fractures (10 injuries, 20%). Three patients died resulting from severe head trauma and extensive burns, but the data does not specify those who died immediately (Katz et al. 1989).

3.11 Victoria Station, London, England, 1991

On 18 February, 1991 a bomb containing approximately 2.3 kg of Semtex (equivalent to 3.1 kg of TNT) was detonated at Victoria Station in London, England. The blast injured a total of 51 people with 29 victims being admitted to the Westminster Hospital. Table 3-11 shows the victims' records and details a total of 64 injuries (2.21 injuries per person) (Johnstone et al. 1993).

Table 3-11 Types of injuries sustained in the Victoria Station bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**4**	--
Hearing Loss	1	--
Perforated Abdominal Viscera	2	--
Perforated Small Bowel	1	--
Soft Tissue Injuries	32	53.33%
Fractures/Defects	18	30.00%
Neurovascular Injury	7	11.67%
Amputations	2	3.33%
Perforated Rectum	1	1.67%
Total Non-Primary Injuries	**60**	

Only 4 injuries were determined to be caused by primary blast effects including 3 perforated abdominal injuries and 1 instance of hearing loss. The remaining 60 non-primary injuries consisted most frequently of soft tissue injuries (32 injuries, 53%) and fractures or defects (18 injuries, 30%). There was one patient whom suffered severe open chest injuries, abdominal injuries, and lacerations to the heart, liver, and bladder. This patient was pronounced dead on arrival to the hospital and was not included in this data (Johnstone et al. 1993).

3.12 Oklahoma City, Oklahoma, United States, 1995

On 19 April, 1995 a vehicle bomb containing the equivalent of 1,814 kg of TNT was detonated at the Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma. The blast injured 759 persons in all with 167 fatalities and 83 survivors admitted to the hospital. Table 3-12 details the 1,895 injuries sustained by the 592 survivors (3.20 injuries per person) (Mallonee et al. 1996).

Table 3-12 Types of injuries sustained in the Oklahoma City bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**272**	--
Eye Injury	59	--
Ear Injury	210	--
Lung Contusion	3	--
Soft Tissue Injuries	1,409	86.81%
Severed Nerves, Tendons, or Ligaments	8	0.49%
Lacerations/Cuts	5	0.31%
Fractures	96	5.91%
Subdural Hematoma	2	0.12%
Head Trauma	80	4.93%
Amputations	1	0.06%
Spinal Cord Injury	1	0.06%
Burns	9	0.55%
Partial Bowel Transection	1	0.06%
Ruptured Kidney	1	0.06%
Acute Respiratory Distress	4	0.25%
Thoracic Injury	6	0.37%
Total Non-Primary Injuries	**1,623**	

A total of 272 injuries were determined to be caused by the primary blast effects. The most common injuries of the non-primary injuries were classified as soft tissue injuries, which included sprains, lacerations, contusions, abrasions, and puncture wounds (1,409 injuries, 87%). Fractures (96 injuries, 6%) and head trauma (80 injuries 5%) were also common injuries among the survivors surveyed. Many of the injured persons attributed glass shattering (flying, broken, or falling) as the source of their injuries; falling debris (ceiling materials, light fixtures, etc.) caused a large number of the injuries as well (Mallonee et al. 1996). It should be noted that limitations to this study include incomplete reporting of minor injuries and persons who received medical treatment after April 25, 1995 or injured persons who did not seek medical treatment were consequently classified as uninjured (Mallonee et al. 1996).

3.13 Khobar Towers, Dhahran, Saudi Arabia, 1996

On 25 June, 1996 a truck bomb containing the equivalent of 9,100 kg of TNT was detonated about 80 feet from the Khobar Towers in Dhahran, Saudi Arabia. The study reports that the bombing caused 574 casualties including 19 deaths, but only 420 persons were injured directly by the bombing and the remaining casualties occurring during evacuation and search and rescue. The direct bombing injuries of the 420 persons lead to 19 deaths, 66 patients hospitalized, 171 treated on an outpatient basis, and 164 self-treated. The hospital records and survey results are listed in Table 3-13 and show a total of 745 injuries for the 401 surviving persons (1.86 injuries per person) (Thompson et al. 2004).

Table 3-13 Types of injuries sustained in the Khobar Towers bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**27**	--
Eye Injury	27	--
Soft Tissue Injuries	434	60.45%
Foreign Body	195	27.16%
Severed Tendons or Ligaments	17	2.37%
Neurovascular Injury	8	1.11%
Lacerations/Cuts	11	1.53%
Partial Ear Amputation/Avulsion	2	0.28%
Fracture/Dislocation	23	3.20%
Thoracic Injury	1	0.14%
Kidney Hematoma and Contusion	1	0.14%
Liver Hematoma and Contusion	1	0.14%
Subdural Hematoma	1	0.14%
Diffuse Axonal Injury	1	0.14%
Concussions	23	3.20%
Total Non-Primary Injuries	**718**	

Eye injuries (27 injuries) were determined to be caused by primary blast effects. The most common injuries among the non-primary injuries were soft tissue injuries (434 injuries, 60%) and foreign body injuries (195 injuries, 27%). It was reported that many of the injuries were caused by glass shattering (flying, broken, or falling) (Thompson et al. 2004).

3.14 Jerusalem, Israel, February - March 1996

Between 25 February, 1996 and 4 March, 1996, four suicide bombings occurred in Jerusalem, Israel. The blasts resulted in a total of 297 casualties including 61 fatalities. Two of the blasts occurred in open air and the other two occurred inside buses, but it was concluded that there is no significant difference in the injuries sustained. The hospital records are listed in Table 3-14 and show a total of 330 injuries for the 297 persons (1.11 injuries per person) (Leibovici et al. 1996).

Table 3-14 Types of injuries sustained in the Jerusalem, Israel between February 1996 and March 1996

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**125**	--
Blast Ear Injury	79	--
Blast Lung	43	--
Blast Abdomen (Intestine)	2	--
Blast Abdomen (Pneumoperitoneum)	1	--
Psychiatric Trauma	59	28.78%
Minor Penetrating Wound or Simple Fracture	19	9.27%
Moderate Penetrating Wound	29	14.15%
Burns	68	33.17%
Amputations	24	11.71%
Ruptured Spleen	6	2.93%
Total Non-Primary Injuries	**205**	

More than a third of the reported injuries were caused by blast effects including abdomen injuries, blast lung, and blast ear injuries. The most often occurring non-primary physical injuries were caused by burns (68 injuries, 33%), moderate penetrating wounds (29 injuries, 14%), and amputations (24 injuries, 12%). An additional 59 injuries (29%) were attributed to psychiatric trauma and emotional shock. The study showed that there is no difference in the injuries (such as penetrating wounds, burns, or traumatic amputations) sustained by those who were injured in the open air bombings or the confined space bombings involving buses (Leibovici et al. 1996).

3.15 Admiral Duncan Public House, Soho, London, England, 1999

On 30 April, 1999 a nail bomb exploded in the Admiral Duncan Public House in Soho, London, England. The blast caused two immediate deaths and two hospitals (Guy's Hospital and St Thomas' Hospital) received a total of 59 patients and admitting only 9. It was assumed all patients not admitted had minor injuries treated and were discharged. Table 3-15 lists the records for the 59 persons and shows a total of 63 injuries (1.07 injuries per person) (Williams and Squires 2000).

Table 3-15 Types of injuries sustained in the Admiral Duncan Public House bombing

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**1**	--
Perforated Colon	1	--
Superficial/Minor Injuries or Wounds	50	80.65%
Burns	3	4.84%

Amputations	2	3.23%
Spinal Cord Injury	1	1.61%
Fracture	4	6.45%
Perforation of the Eye	1	1.61%
Penetrating Injury	1	1.61%
Total Non-Primary Injuries	**62**	

The only injury caused by the primary blast effects was a perforated colon that was not caused by a penetrating injury. Most of the remaining 62 injuries were superficial or minor wounds (50 injuries, 81%) and constitute the 50 victims that were treated and not admitted to the hospital. For the 9 patients admitted, 3 were treated for burns, 4 fractures were treated, and 2 amputations were performed.

3.16 Israel, October 2000 – December 2005

Between October 2000 and December 2005 more than 250 persons were killed and 2,022 additional casualties resulted from all terrorist acts, which include bombings, shootings, etc. around Israel. Records show that 837 patients, under the age of 46, were hospitalized due to 107 terrorist bombings. The data from the Israel National Trauma Registry are listed in Table 3-16 and shows a total of 2,494 injuries for the 837 patients (2.98 injuries per person) (Jaffe and Peleg 2010).

Table 3-16 Types of injuries sustained in the Israel bombings between 2000 and 2005

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**0**	--
Fractures	362	14.51%
Internal Injury	297	11.91%
Open Wound	640	25.66%
Contusions/Bruises	391	15.68%
Dislocations, Sprains, Strains, Amputations, Crushes, Injuries to Blood Vessels or Nerves, or Other Unspecified Injuries	322	12.91%
System-Wide Injury	354	14.19%
Burns	128	5.13%
Total Non-Primary Injuries	**2,494**	

For all of the blasts that occurred, none of the reported injuries were determined to be caused by the primary blast effects. The most common injuries were open wounds (640 injuries, 26%), followed by contusions or bruises (391 injuries, 16%), fractures (362 injuries, 15%), and system-wide injuries (354 injuries, 14%). The report states that 544 of the injuries were caused by penetrating foreign objects (50%), 413 were blunt force (38%), and 124 were burn related (11%) (Jaffe and Peleg 2010).

3.17 Madrid, Spain, 2004

On 11 March, 2004 a total of 10 terrorist bombings occurred in the early morning on four different trains in Madrid, Spain. The detonations caused over 2,000 casualties and 191 deaths. The data gathered for 775 casualties that were taken to 7 different hospitals omits superficial

bruises, transient hearing loss, and emotional shock from 263 casualties. Detailed in Table 3-17, the records show a total of 1,102 injuries for the remaining 512 victims (2.15 injuries per person) (Turégano-Fuentes et al. 2008).

Table 3-17 Types of injuries sustained in the Madrid, Spain bombings

Injury Type	Total Injuries	% of Total Non-Primary Injuries
Primary Blast Injuries	**464**	--
Eye Injury	95	--
Blast Lung Injury	43	--
Lung Contusion	58	--
Abdominal Injury	28	--
Tympanic Perforation	240	--
Fractures/Mangled Limbs	194	30.41%
Amputations	6	0.94%
Neurovascular Injury	9	1.41%
Penetrating Injury	211	33.07%
Burns	103	16.14%
Brain Contusion	9	1.41%
Hematoma	9	1.41%
Hemorrhage	11	1.72%
Inhalation Injury	2	0.31%
Head Trauma	16	2.51%
Ear Lobe Amputation	13	2.04%
Thoracic Injury	44	6.90%
Flail Chest	2	0.31%
Spinal Cord Trauma without Spine Fracture	8	1.25%
Cardiac Tamponade	1	0.16%
Total Non-Primary Injuries	**638**	

A total of 464 injuries were attributed to primary blast effects which included eye injuries, ear injuries, lung injuries, and non-penetrating abdominal organ injuries. Of the non-primary injuries, the most common injuries were penetrating foreign object injuries (211 injuries, 33%), fractures or mangled limbs (194 injuries, 30%), and burns (103 injuries, 16%). It should be noted that the omitted records for the 263 casualties included superficial bruises, mild contusions, transient hearing loss without eardrum perforations, and/or psychiatric trauma that could not be placed into an injury type category and may skew the results.

3.18 Pakistan, 2007-2009

Between 2007 and 2009, over 100 terrorist suicide bombings occurred in Northern Pakistan with many of the casualties being treated at the Combined Military Hospital in Rawalpindi. The hospital trauma registry showed the records of 1,296 patients were terrorism victims with 170 patients with minor injuries being sent home after minor treatment. The 1,296 victims were presented with a total of 5,390 injuries (4.16 injuries per person) as detailed in Table 3-18 (Yasin et al. 2012).

Table 3-18 Types of injuries sustained in the Pakistan bombings between 2007 and 2009

Injury Type	Total Injuries	% of Total Non-Primary Injuries

Primary Blast Injuries	**599**	--
Ear Injury	428	--
Eye Injury	29	--
Blast Lung Injury	142	--
Muscular Penetrating Injuries	1,127	23.52%
Fractures	1,043	21.77%
Neurovascular Injury	237	4.95%
Penetrating Gastrointestinal Injury	962	20.08%
Perineal Injuries	25	0.52%
Thoracic Injury	535	11.17%
Penetrating Chest Trauma	368	7.68%
Blunt Chest Trauma	60	1.25%
Head Injury	143	2.98%
Spinal Cord Damage	60	1.25%
Head Injury with Spinal Cord Damage	14	0.29%
Urogenital Trauma	91	1.90%
Amputations	121	2.53%
Ear Amputation	5	0.10%
Total Non-Primary Injuries	**4,791**	

The primary blast effects caused 599 injuries, including abdominal organ lacerations without penetrating trauma. For the remaining non-primary injuries, the majority of the injuries were muscular penetrating injuries (1,127 injuries, 24%) and fractures (1,043 injuries, 22%). Internal hollow and solid viscous injuries were all reported to be caused by multiple splinter injuries in the abdomen and not by primary blast effects (Yasin et al. 2012).

4.0 Blast Analysis

The collective data consist of 9,109 casualties and 732 fatalities, shown in Table 4-1. Details on the numbers and types of injuries from 6,554 casualties were obtained for analysis in our work. For those 6,554 injured persons, a total of 16,699 injuries were sustained[1] (2.55 injuries per person) and 1,952 injuries (11.7%) were determined to be from primary blast effects. Figure 4-2 shows how the other injuries are broken down: 4,770 injuries (28.6%) as secondary, 8,506 injuries (50.9%) as tertiary, and 1,471 injuries (8.8%) as quaternary. Figure 4-1 shows the most common physical injuries not caused by primary blast effects include penetrating and perforating wounds from glass or other foreign objects, fractures, and soft tissue injuries. Shown in red in Figure 4-1 are the primary blast injuries and non-physical injuries. The complete list detailing the type of wound injuries for each blast are detailed for each case study in the Appendix.

Table 4-1 Summary of the 18 terrorist bombing case studies

Case Studies	TNT Equivalent of Blast	No. of Explosions	Population Evaluated	No. of Injuries	Injuries/ Person
Belfast	-	110	1,532	2,599	1.70
Old Bailey	80 kg	1	154	151	0.98
Tower of London	5 kg	1	19	89	4.68
Guildford	5 kg	2	24	42	1.75
Birmingham	5 kg	2	42	84	2.00
Craigavon	-	77	339	740	2.18
Italy	20 kg	1	107	250	2.34
Paris	-	11	205	461	2.25
Berlin	5 kg	1	80	105	1.31
Jerusalem (1988)	6 kg	1	29	95	3.28
Victoria Station	3.1 kg	1	29	64	2.21
Oklahoma City	1,814 kg	1	592	1,895	3.20
Dhahran	9,100 kg	1	401	745	1.86
Jerusalem (1996)	-	4	297	330	1.11
Soho	-	1	59	63	1.07
Israel	-	107	837	2,494	2.98
Madrid	-	10	512	1,102	2.15
Pakistan	-	100	1,296	5,390	4.16
Total	**-**	**432**	**6,554**	**16,699**	**2.55**

[1] Not all case studies published minor wounds, lacerations, cuts, bruises, etc. which is a limitation in the study. Inconsistent reporting among cases studies limits the ability to reliably compare data across studies.

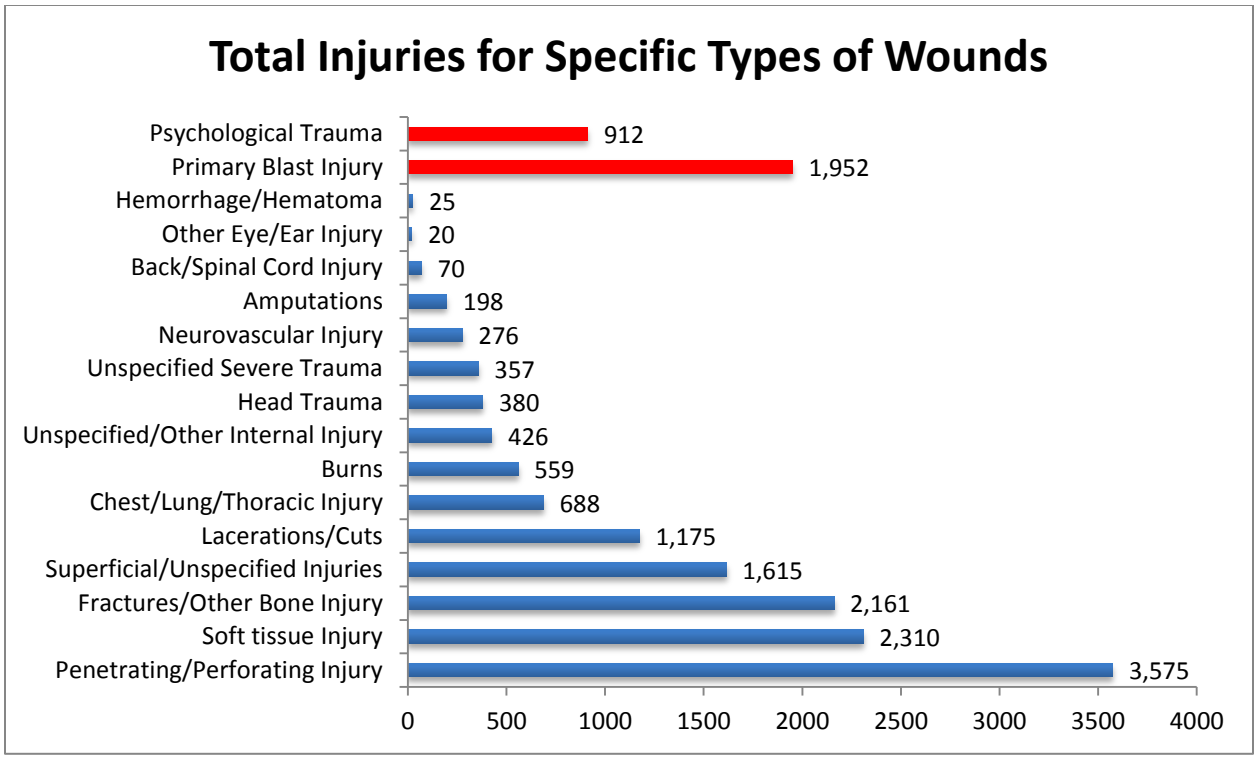

Figure 4-1 Total injuries for specific types of wounds for the 18 case studies

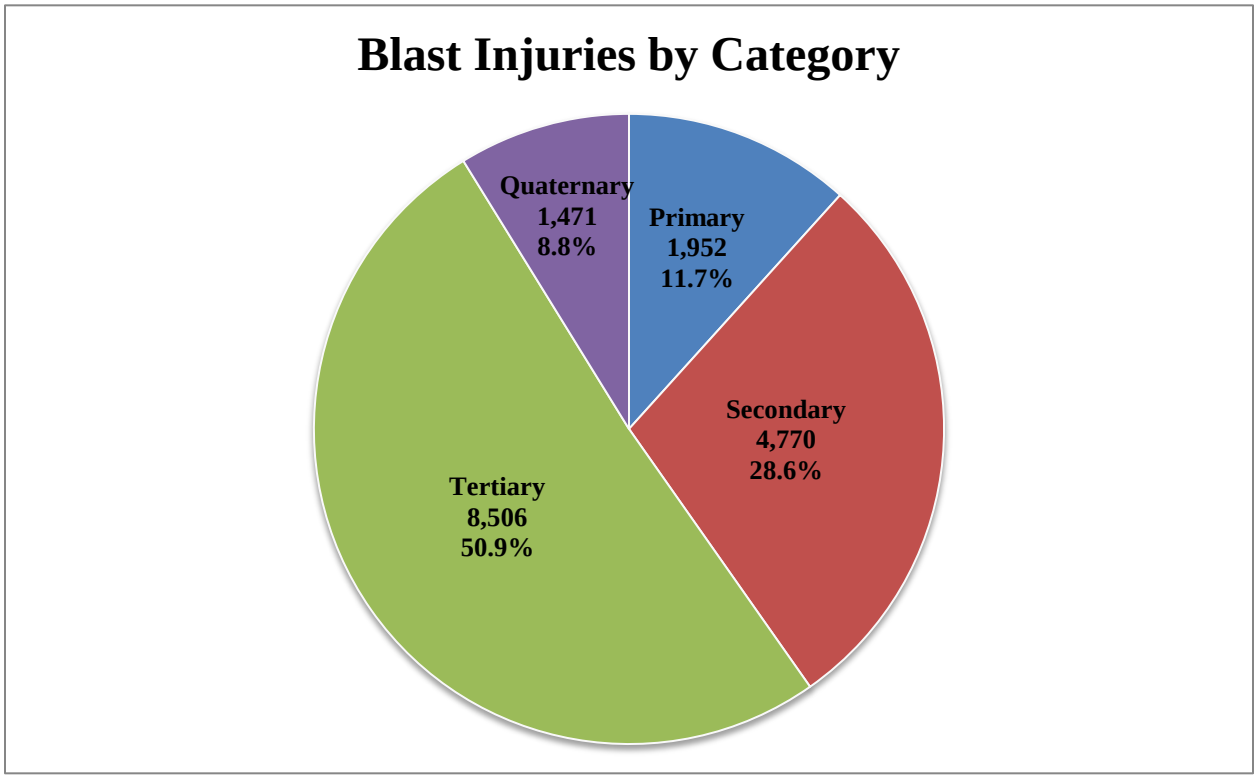

Figure 4-2 Injuries for specific categories of wounds for the 18 case studies

5.0 Earthquake Results

The data collected on eight case studies that review earthquake injuries are reviewed and analyzed in Sections 5.1 to 5.8.

5.1 Mexico City, Mexico, 1985

On 19 September and again on 20 September, 1985 two earthquakes with a magnitude of 8.1 and 6.5 on the Richter scale, respectively, occurred in Mexico City, Mexico. The total population affected by the two quakes is unknown, but medical records were reviewed from 14 emergency departments for injuries sustained within 72 hours of the first earthquake. A total of 171 inpatient and outpatient records were reviewed and show 707 injuries (4.13 injuries per person) (Sanchez-Carrillo 1989).

Table 5-1 Types of injuries sustained in the Mexico City, Mexico earthquakes

Injury Type	Total Injuries	% of Total Injuries
Multiple Traumas	129(x2)	36.49%
Fractures	73	10.33%
Contusions/Bruises	142	20.08%
Wounds	82	11.60%
Other	47	6.65%
Psychological Trauma	100	14.14%
Unspecified Crush Injury	5	0.71%
Total	**707**	

The most common injuries experienced were simple contusions or bruises (142 injuries, 20%) and the more complex injury type of "multiple traumas" (assumed to be two injuries) (258 injuries, 36%). It is unclear what the total number of injuries sustained by these persons would be, but it is most certainly more than one injury per person. Psychological trauma was reported by 100 of the 171 patients (58%); however psychological trauma or emotional shock is not reported by most of the other case studies and will not be used in the overall analysis since it is not a physical injury.

5.2 Hanshin-Awaji, Japan, 1995

On 17 January, 1995 an earthquake with a magnitude of 7.2 on the Richter scale occurred in the Hanshin-Awaji area of Japan. Over 200,000 homes were damaged or destroyed resulting in 41,000 casualties and 5,000 fatalities. Most of these deaths were caused by crush injuries from collapsed buildings and 504 deaths were fire related. A total of 2,718 patients were admitted to hospitals with 3,534 injuries (1.30 injuries per person) (Nakamori et al. 1997).

Table 5-2 Types of injuries sustained in the Hanshin-Awaji, Japan earthquake

Injury Type	Total Injuries	% of Total Injuries
Burns	45	1.27%
Unspecified Crush Injury	422	11.94%
Head Trauma	61	1.73%

Thoracic Injury	84	2.38%
Abdominal Injury	86	2.43%
Fractures	1,500	42.44%
Other	1,336	37.80%
Total	**3,534**	

The most common physical injuries reported were fractures (1,500 injuries, 42%) and other unspecified injuries contributed an additional 1,336 injuries (38%). A total of 45 patients sustained burns with the majority of the burns (30 persons) being caused by a hot liquid (scald burns). The remaining burn victims had flame or chemical burns which were the result of house fires which started after either the home collapsed or from a gas explosion (Nakamori et al. 1997).

5.3 Marmara, Turkey, 1999

On 17 August, 1999 an earthquake with a magnitude of 7.4 on the Richter scale occurred in Marmara, Turkey. The quake caused 43,953 casualties and killed 17,480 people. Records from the Hospital of Medicine Faculty of Uludag University show a total of 645 persons with earthquake related injuries were admitted between 17 August and 4 October, 1999. A total of 263 patients with earthquake related trauma were included in the analysis and had sustained 414 injuries (1.57 injuries per person) (Bulut et al. 2005).

Table 5-3 Types of injuries sustained in the Marmara, Turkey earthquake

Injury Type	Total Injuries	% of Total Injuries
Unspecified Crush Injury	110	26.57%
Fractures/Dislocations	109	26.33%
Other Extremity Injury	104	25.12%
Chest Injury	20	4.83%
Abdominal Injury	19	4.59%
Head Trauma	18	4.35%
Other Unspecified Injury	34	8.21%
Total	**414**	

Crush injuries were the most common reported (110 injuries, 27%), closely followed by fractures or dislocations (109 injuries, 26%) and unspecified extremity injuries (104 injuries, 25%).

5.4 Gujarat, India, 2001

On 26 January, 2001 an earthquake with a magnitude of 7.7 on the Richter scale occurred in the North-East of Bhuj city in Gujarat, India. Over 165,000 persons were injured and 20,005 were killed. The records at Bidada Hospital reviewed show 1,248 patients with earthquake related injures between 26 January, 2001 and 4 April, 2001. There were 534 cases that could be analyzed for injury type that showed a total of 572 injuries (1.07 injuries per person) (Phalkey et al. 2011).

Table 5-4 Types of injuries sustained in the Gujarat, India earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures/Dislocations	306	53.50%

Soft Tissue Injury	119	20.80%
Unspecified Crush Injury	31	5.42%
Neurovascular Injury	6	1.05%
Amputations	38	6.64%
Other Health Condition than Injury	72	12.59%
Total	**572**	

More than half of the injuries experienced were fractures or dislocations (306 injuries, 54%) and an additional 119 injuries were soft tissue injuries (21%). Injuries reported as "other health condition than injury" included cases of hernia (10 cases), COPD (9 cases), and diabetic complications (4 cases) as well as many other conditions that required treatment. These injuries will be excluded from the physical injury analysis.

5.5 Kashmir, India, 2005

On 8 October, 2005 an earthquake with a magnitude of 7.4 on the Richter scale occurred near Kashmir, India. The quake caused 1,308 deaths and 6,622 casualties within the districts of Baramulla, Poonch, Kupwara, and Srinagar and causing a total of 60,000 deaths across the entire state. The records of 166 patients were collected from the Accident and Emergency Department of the Sheri Kashmir Institute of Medical Sciences. Assuming patients categorized as "polytrauma" had two injuries then the total number of injuries is 181 (1.09 injuries per person) (Yatoto et al. 2009).

Table 5-5 Types of injuries sustained in the Kashmir, India earthquake

Injury Type	Total Injuries	% of Total Injuries
Head Trauma	100	55.25%
Fractures/Dislocations	28	15.47%
Soft Tissue Injury	10	5.52%
Abdominal Injury	5	2.76%
Chest Injury	3	1.66%
Neurovascular Injury	3	1.66%
Unspecified Crush Injury	2	1.10%
Multiple Trauma	15(x2)	16.57%
Total	**181**	

The most prominent injury reported was head trauma (100 injuries, 55%), but it is unclear if the data presented only the most predominate injuries or if each case other than those stated as "polytrauma" sustained only one injury.

5.6 Sichuan, China, 2008

On 12 May, 2008 an earthquake with a magnitude of 8.0 on the Richter scale struck the eastern Sichuan Province of China killing 69,142 and seriously injuring more than 374,000. A total of 205 records for patients with musculoskeletal injuries admitted to the First and Second Affiliated Hospitals of Chongqing Medical University between 13 May and 10 June, 2008 were reviewed. The records show a total of 572 injuries for the 205 patients (2.79 injuries per person) (Dai et al. 2010).

Table 5-6 Types of injuries sustained in the Sichuan, China earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	349	61.01%
Compartment Syndrome	18	3.15%
Soft Tissue Injury	21	3.67%
Unspecified Crush Injuries	59	10.31%
Amputations	10	1.75%
Thoracic Injury	15	2.62%
Abdominal Injury	9	1.57%
Acute Renal Failure	10	1.75%
Head Trauma	8	1.40%
Paraplegia associated with Vertebral Fracture	12	2.10%
Neurovascular Injury	61	10.66%
Total	**572**	

The most common injuries reported were fractures (349 injuries, 61%) with the majority of fractures occurring in the extremities (239 fractures). 12 of the vertebral fractures resulted in paraplegia of the patient.

5.7 Padang, Indonesia, 2009

On 30 September 2009, an earthquake with a magnitude of 7.6 on the Richter scale occurred off of the coast of Padang, Indonesia killing 1,117 people and injuring 3,515. A survey of 184 adult injured survivors that fit Sudaryo et al's inclusion criteria was conducted to determine the types of injuries expected. The survey returned a total of 254 injuries for the patients (1.38 injuries per person) (Sudaryo et al. 2012).

Table 5-7 Types of injuries sustained in the Padang, Indonesia earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures/Dislocations	72	28.35%
Soft Tissue Injury	46	18.11%
Lacerations/Cuts/Punctures	49	19.29%
Contusions/Bruises	75	29.53%
Others including burn	12	4.72%
Total	**254**	

Contusions and bruises were the predominant types of injury (75 injuries, 30%) with fractures and dislocations a close second (72 injuries, 28%). The authors of this study note that data collection was limited due to the fact that many injuries were not documented in medical records because either the hospital did not make complete records or the records were lost (Sudaryo et al. 2012). Therefore, the total injuries observed in the case study do not accurately reflect the total injuries that occurred in the disaster.

5.8 Van, Turkey, 2011

On 23 October 2011, an earthquake with a magnitude of 7.2 on the Richter scale occurred in Van, Turkey. There were 604 deaths reported and 72,242 buildings damaged and thousands of injuries that required immediate treatment. The records for 285 patients that were admitted to Van Training and Research Hospital and classified as earthquake related injuries were reviewed.

The records show that the patients suffered from a total of 541 injuries (1.90 injuries per person) (Görmeli et al. 2012).

Table 5-8 Types of injuries sustained in the Van, Turkey earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	295	54.53%
Lacerations/Cuts	75	13.86%
Soft Tissue Injury	20	3.70%
Unspecified Crush Injury	46	8.50%
Compartment Syndrome	28	5.18%
Thoracic Injury	17	3.14%
Abdominal Injury	17	3.14%
Head Trauma	14	2.59%
Acute Renal Failure	22	4.07%
Amputations	7	1.29%
Total	**541**	

Fractures alone accounted for 295 of the injuries experienced by the 285 patients (55%) with the majority of the fractures occurring in the extremities (202). An additional 75 lacerations and cuts were reported in the records (14%).

6.0 Earthquake Analysis

Over 500,000 earthquakes are estimated to occur each year resulting in more than 8,000 fatalities and 26,000 casualties (Alexander 1985). For the eight earthquake case studies, details in the injuries of 4,526 persons were obtained and evaluated. A total of 6,775 injuries were observed in the 4,526 persons, an average of 1.50 injuries per person (see Table 6-1).

Table 6-1 Average number of injuries per person for the earthquake case studies

Case Studies	Magnitude	Population Evaluated	No. of Injuries	Injuries/ Person
Mexico City	8.1	171	707	4.13
Hanshin-Awaji	7.2	2,718	3,534	1.30
Marmara	7.4	263	414	1.57
Gujarat	7.7	534	572	1.07
Kashmir	7.4	166	181	1.09
Sichuan	8.0	205	572	2.79
Padang	7.6	184	254	1.38
Van	7.2	285	541	1.90
Overall	**-**	**4,526**	**6,775**	**1.50 (average)**

The total casualties for specific wound types are presented in Figure 6-1 with the non-physical injuries and other health conditions than injury shown in red. The most common wound types include fractures and dislocations (2,732 injuries) and unspecified crush injuries (675 injuries). Figure 6-1 illustrates the most common cause of injury occurred from building collapse (either being hit, trapped, or crushed) which leads to fractures, soft tissue injury, injuries categorized as multiple traumas, and many others. The complete list detailing the type of wound injuries for each earthquake are shown for each case study in the Appendix.

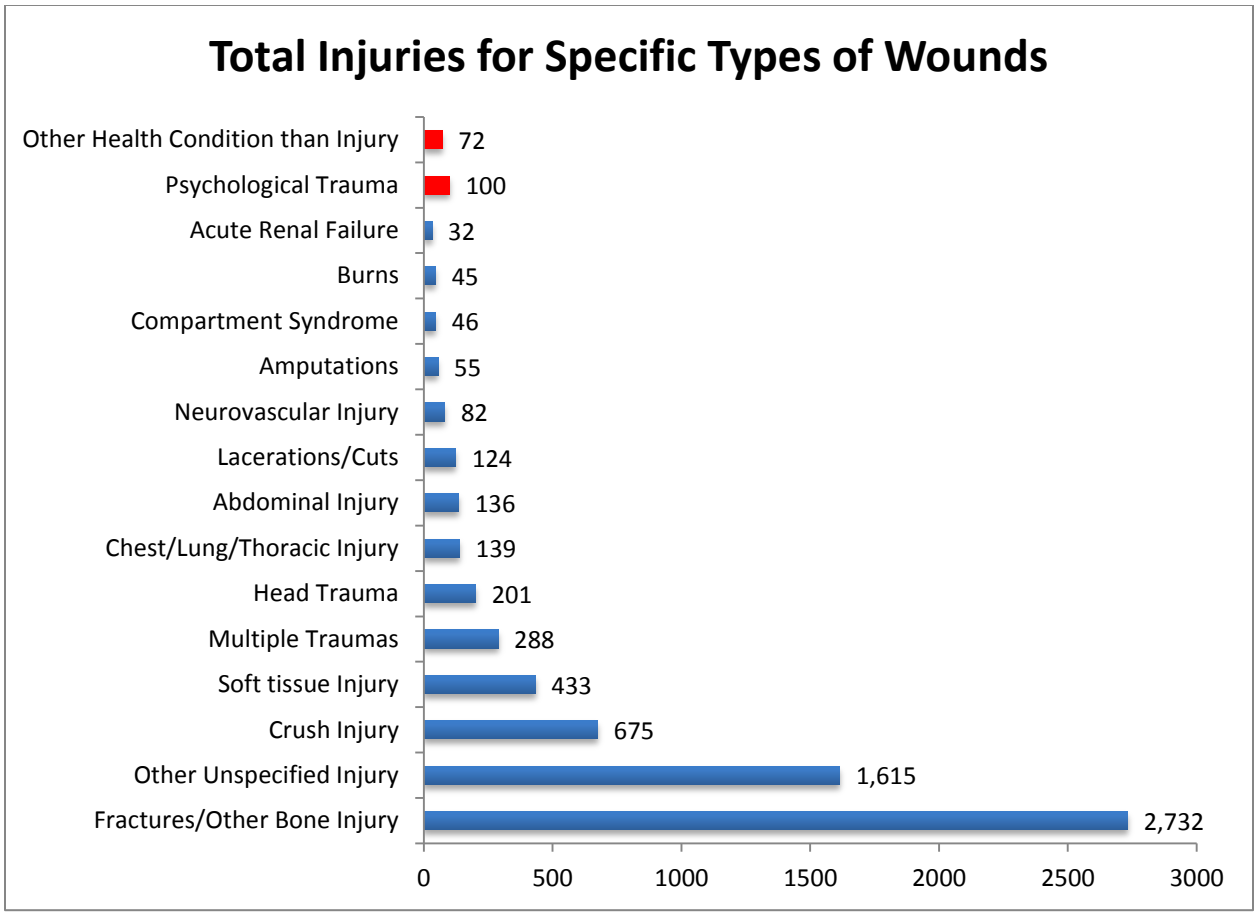

Figure 6-1 Total injuries for specific wound types observed in the 8 earthquake case studies.

The data collection for earthquake injuries focused on major earthquakes with a magnitude greater than 7.0 on the Richter scale. Many of the specific injuries described in the case studies could have been caused by falling debris and building collapse and therefore could be categorized as "crush" injury. By listing the specific types of crush injury, a better spectrum of the types of injury resulting from building collapse can be fleshed out. Even though the total injuries reported in the earthquake case studies do not represent the total injuries and populations affected in each case, data obtained from these case studies still provide representative data and valuable insight on the spectrum and quantity of injuries observed in earthquakes scenarios.

7.0 Discussion

The review of case studies on terrorist bombings and earthquakes can provide valuable insight on the types of injuries that may occur after an improvised nuclear device (IND) scenario. Blast from bombings and earthquakes can result in overpressure, tumbling, debris, burn, and crush injuries that have particular relevance to the type of injuries that might result from an IND. Therefore, injuries from terrorist bombings not related to the primary blast effects and injuries occurring after earthquakes were reviewed according to case study data available in the open literature. The previous sections detail the spectrum and quantity of injuries resulting from blasts and earthquakes, thereby providing valuable information for preparedness and response planning for an IND. Knowledge concerning anticipated number and types of injuries that might be encountered after an IND provide data for casualty estimation and help inform medical response planning and resource requirements.

In the case of the blast studies that were evaluated, the main causes of injuries were from shattered glass and foreign objects and whole body displacement which occurred because of the force of the blast wave. The most dominant types of injury observed were penetrating or perforating wounds, soft tissue injuries, and fractures or other bone injuries. The size of the blast region in an urban setting can range from relatively localized area near the point of explosion to approximately 10 blocks as seen in the Oklahoma City Bombing (Mallonee et al. 1996).

For the earthquake studies, the prevailing causes of injuries were likely caused by falling and being hit or trapped in the event of a building collapse. The most common types of injuries included fractures, unspecified crush injuries, and various soft tissue injuries. The effects of the earthquakes in urban settings could be observed over a thousand miles away where building sway has been experienced (Dai et al. 2010). While the total population affected by an earthquake is typically much larger than the population affected by a terrorist explosions the overall quantity and spectrum of injuries for both are relevant to understanding the patterns of injuries that would be caused by an IND.

An urban IND incident would cause substantial damage to buildings and fires. While most of the studies reported that building damage occurred, only a handful of the case studies had a fire start because of a bombing. Burns are often sustained, but they are mostly categorized as flash burns from the short exposure to luminous heat that can cause any degree of burn. The over-pressurization injuries, blast wind injuries, debris injuries, burn injuries, and crush injuries that were documented in the cases pertain to the expected effects in the event of an IND. Rarely does a terrorist bombing result in a complete building collapse, but some of the studies exhibit partial building collapse or structural damage which inflicted injuries.

8.0 Limitations and Future Work

There are a few limitations worth noting. Not all cases specified what type of injury occurred or where on the body an injury occurred. For example, some cases only reported how many persons had an arm injury. This may include lacerations, amputations, cuts, fractures, etc. However, if the specific type of injury was not indicated, it could not be included in the tally for a specific injury type.

There are a number of limitations to the blast data. Not all cases used medical records to create the data provided. Some cases used surveys from the patients who evaluated their injuries. Some of the surveys that were sent out to the surviving victims were sent out months or years later, not directly after the incident. Even data originating from medical records has uncertainties since physicians and nurses were working under austere circumstances during the days following such disasters. Considering higher than normal patient demands, details concerning injuries may be vague and inclusion of details on minor injuries, lacerations, abrasions, bruises, etc. may be neglected due to time constraints. Most of the studies do not have firm details on the total population injured or affected from the individual incidents, but the case studies instead consisted of a selection from the incident for which details are available. For example, the bombing in Madrid, Spain on March 11, 2004 resulted in around 2,000 casualties, but the data from only 512 victims were evaluated in this particular case study. Since the case studies examined in our work do not represent the total population affected, one cannot conclude that the spectrum of injuries reported here are the only injuries that occur in these types of incidents and the most common injuries observed may not be completely accurate, in particular with respect to minor injuries that would be more likely neglected in reporting after such disasters.

Just as with the case study review for terrorist bombings, the earthquake case study review represents only a sample of the total impact. Earthquakes generally affect a large area, and the earthquake case studies represent only a portion of the total population affected. Therefore, data from the selected case studies are not comprehensive for all of the injuries or causes of injury in the affected population for any given earthquake. The types of buildings that collapsed in the earthquake studies were not described in the selected reports. The specific types of structures involved in the earthquakes may impact the spectrum of injuries resulting from a collapse.

In spite of all the limitations, these collective data provide a valuable insight to the types of injuries that may occur after an IND scenario. The focus of the work presented here was to improve our understanding of the types and numbers of injuries that result in the urban setting with events that have comparable effects. Our aim was to gain insight into which injuries occur from urban structures when they are devastated either by blast or earthquake. Parallels can be drawn between the nature of these effects and potential effects from an IND. Therefore, the specific aim of this study was to collect data on the types of injuries that have occurred after terrorist bombings and earthquakes with particular emphasis on injuries resulting from urban structures.

More information could be gleaned with further analysis, such as examination of details on environments to make more relevant correlations with nuclear weapons effects.

Appendix

A.1. Complete list of Blast Injuries

Table A-1 through Table A-18 list the injuries sustained for each bombing as detailed in the case studies.

Table A-1 Complete list of injuries sustained in the Belfast bombings

Wound Type	Total Injuries	% of Total Injuries
Lacerations	860	33.09%
Abrasions	359	13.81%
Bruises/Contusions	244	9.39%
Fractures	104	4.00%
Dislocations	1	0.04%
Sprains	38	1.46%
Concussion	34	1.31%
Brain Laceration	3	0.12%
Peripheral Vessel Injury	1	0.04%
Nerve Damage	7	0.27%
Amputations	20	0.77%
Eye Injury	12	0.46%
Unilateral Perforated Tympanic Membrane	10	0.38%
Bilateral Perforated Tympanic Membrane	5	0.19%
Hearing Loss	67	2.58%
Chest Injury	10	0.38%
Blast Lung	2	0.08%
Burn	50	1.92%
Emotional Shock	772	29.70%
Total	**2,599**	

Table A-2 Complete list of injuries sustained in the Old Bailey bombing

Wound Type	Total Injuries	% of Total Injuries
Minor Cuts	52	34.44%
Minor Abrasions	59	39.07%
Other minor injuries	24	15.89%
Loss of Consciousness/Emotional Shock	7	4.64%
Severe Lacerations	3	1.99%
Major Vascular Injuries	3	1.99%
Fractures	3	1.99%
Total	**151**	

Table A-3 Complete list of injuries sustained in the Tower of London bombing

Wound Type	Total Injuries	% of Total Injuries
Serious Soft Tissue Damage	17	19.10%
Fractures other than Skull	20	22.47%
Frontal Lobe and Brain Stem Damage	1	1.12%
Facial/Skull Fracture	4	4.49%
Concussion	1	1.12%
Ear Injury	22	24.72%
Burns	10	11.24%
Eye Damage	4	4.49%
Abdominal Injury	2	2.25%

Open Joint Injuries	2	2.25%
Pulmonary Contusion	2	2.25%
Psychiatric Trauma	4	4.49%
Total	**89**	

Table A-4 Complete list of injuries sustained in the Horse and Groom and Seven Stars Public Houses bombings

Wound Type	Total Injuries	% of Total Injuries
Serious Soft Tissue Damage	11	26.19%
Burns	10	23.81%
Eardrum Rupture	9	21.43%
Fractures	7	16.67%
Eye Damage	3	7.14%
Blast Lung	2	4.76%
Total	**42**	

Table A-5 Complete list of injuries sustained in the Tavern in Town and Mulberry Bush Public Houses bombings

Wound Type	Total Injuries	% of Total Injuries
Burns	23	27.38%
Serious Soft Tissue Damage	22	26.19%
Eardrum Rupture	17	20.24%
Fractures	13	15.48%
Eye Damage	6	7.14%
Blast Lung	3	3.57%
Total	**84**	

Table A-6 Complete list of injuries sustained in the Northern Ireland bombings

Wound Type	Total Injuries	% of Total Injuries
Wounds	188	25.41%
Abrasions	199	26.89%
Burn	6	0.81%
Fractures	127	17.16%
Vascular Damage	4	0.54%
Above Knee Amputation	4	0.54%
Below Knee Amputation	4	0.54%
Forearm Amputation	3	0.41%
Humerus Amputation	1	0.14%
Penetrating Abdomen Injury	8	1.08%
Penetrating Chest Injury	4	0.54%
Head Injury	13	1.76%
Perforating Eye Injury	16	2.16%
Ear Injury	93	12.57%
Emotional Shock	70	9.46%
Total	**740**	

Table A-7 Complete list of injuries sustained in the Bologna, Italy bombings

Wound Type	Total Injuries	% of Total Injuries
Skull Fracture	10	4.00%
Brain Contusion	6	2.40%
Concussion	27	10.80%
Ear Injury	15	6.00%
Eye Injury	7	2.80%
Chest Wall Injury	11	4.40%
Pneumothorax	4	1.60%
Subcutaneous Emphysema	1	0.40%

Lung Contusion	4	1.60%
Abdominal Injury	7	2.80%
Fractured Scapula	4	1.60%
Fractured Humerus	6	2.40%
Fractured Radius/Ulna	8	3.20%
Fractured Hand	6	2.40%
Fractured Femur	4	1.60%
Fractured Tibia/Fibula	8	3.20%
Fractured Ankle	5	2.00%
Fractured Foot	7	2.80%
Fractured Spine	7	2.80%
Forearm Amputation	1	0.40%
Digit Amputation	2	0.80%
Superficial Wounds	57	22.80%
Lacerations	15	6.00%
Burns	28	11.20%
Total	**250**	

Table A-8 Complete list of injuries sustained in the Paris, France bombings

Wound Type	Total Injuries	% of Total Injuries
Abrasions/Lacerations	139	30.15%
Burns	100	21.69%
Other Skin Lesions	56	12.15%
Fractures other than Skull	54	11.71%
Ear Blast Lesion	39	8.46%
Perforated Eardrum	27	5.86%
Lung Blast Injury	6	1.30%
Pulmonary Contusion	1	0.22%
Hemopneumothorax	1	0.22%
Pneumomediastinum	1	0.22%
Eye Lesion	12	2.60%
Amputation	6	1.30%
Abdominal Injury	8	1.74%
Head Trauma	8	1.74%
Open Skull Fracture	3	0.65%
Total	**461**	

Table A-9 Complete list of injuries sustained in the LaBelle Disco bombing

Wound Type	Total Injuries	% of Total Injuries
Perforated Tympanic Membrane	42	40.00%
Burns	16	15.24%
Abrasions/Contusions	12	11.43%
Superficial Injury	12	11.43%
Eye Injury	1	0.95%
Severe Multiple Trauma	3	2.86%
Orthopedic Related Injury	8	7.62%
Laceration/Penetrating Injury	11	10.48%
Total	**105**	

Table A-10 Complete list of injuries sustained in the Jerusalem, Israel bombing in 1988

Wound Type	Total Injuries	% of Total Injuries
Perforated Eardrum	22	23.16%
Blast Lung	11	11.58%
Blast Abdomen	4	4.21%
Perforated Ileum	1	1.05%

Perforated Colon	1	1.05%
Peritoneal-Signs	2	2.11%
Head Trauma	4	4.21%
Eye Injury	5	5.26%
Fractured Ribs	3	3.16%
Flail Chest	3	3.16%
Pneumothorax	2	2.11%
Hemothorax	2	2.11%
Myocardial Contusion	2	2.11%
Amputation	1	1.05%
Fractured Limbs	7	7.37%
Burns	5	5.26%
Lacerations of Soft Tissue	20	21.05%
Total	**95**	

Table A-11 Complete list of injuries sustained in the Victoria Station bombing

Wound Type	Total Injuries	% of Total Injuries
Soft tissue injuries	32	50.00%
Fractures	13	20.31%
Bone Defect	5	7.81%
Neurovascular Damage	7	10.94%
Traumatic Amputation	2	3.13%
Perforated Abdominal Viscera	2	3.13%
Perforated Small Bowel	1	1.56%
Perforated Rectum	1	1.56%
Hearing Loss	1	1.56%
Total	**64**	

Table A-12 Complete list of injuries sustained in the Oklahoma City bombing

Wound Type	Total Injuries	% of Total Injuries
Soft Tissue Injury	1,022	53.93%
Musculoskeletal Injury	210	11.08%
Severed Nerves, Tendons, or Ligaments	8	0.42%
Bone Laceration	2	0.11%
Fracture	84	4.43%
Musculoskeletal Sprain	177	9.34%
Skull Fracture	6	0.32%
Subdural Hematoma	2	0.11%
Head Injury	72	3.80%
Severe Brain Injury	8	0.42%
Skull Fracture	6	0.32%
Leg Amputation	1	0.05%
Spinal Cord Injury	1	0.05%
Eye Injury	59	3.11%
Burns	9	0.47%
Ear Injury	210	11.08%
Partial Bowel Transection	1	0.05%
Lacerated Spleen	2	0.11%
Ruptured Kidney	1	0.05%
Lacerated Liver	1	0.05%
Acute Respiratory Distress	4	0.21%
Pneumothorax	6	0.32%
Lung Contusion	3	0.16%
Total	**1,895**	

Table A-13 Complete list of injuries sustained in the Khobar Towers bombing

Wound Type	Total Injuries	% of Total Injuries
Soft Tissue	380	51.01%
Foreign Body	195	26.17%
Lacerated Tendons	15	2.01%
Severed Nerve	5	0.67%
Severed Artery/Vein	3	0.40%
Severed Ligament	2	0.27%
Severe Laceration	11	1.48%
Partial Ear Amputation/avulsion	2	0.27%
Eye Injury	27	3.62%
Fracture/Dislocation - Upper Extremity	11	1.48%
Fracture/Dislocation - Lower Extremity	3	0.40%
Fracture/Dislocation - Facial	3	0.40%
Fracture/Dislocation - Rib	3	0.40%
Fracture/Dislocation - Vertebrae	2	0.27%
Hemothorax	1	0.13%
Kidney Hematoma and Contusion	1	0.13%
Liver Hematoma and Contusion	1	0.13%
Open Skull Fracture	1	0.13%
Subdural Hematoma	1	0.13%
Diffuse Axonal Injury	1	0.13%
Concussion	23	3.09%
Strain or Sprain	54	7.25%
Total	**745**	

Table A-14 Complete list of injuries sustained in the Jerusalem, Israel bombings between February 1996 and March 1996

Wound Type	Total Injuries	% of Total Injuries
Psychological Stress	59	17.88%
Blast Ear Injury	79	23.94%
Minor Penetrating Wound or Simple Fracture	19	5.76%
Moderate Penetrating Wound	29	8.79%
Blast Lung	43	13.03%
Blast Abdomen (Intestine)	2	0.61%
Blast Abdomen (Pneumoperitoneum)	1	0.30%
Burns	68	20.61%
Amputations	24	7.27%
Ruptured Spleen	6	1.82%
Total	**330**	

Table A-15 Complete list of injuries sustained in the Admiral Duncan Public House bombing

Wound Type	Total Injuries	% of Total Injuries
Minor Injuries (not admitted)	50	79.37%
Burns	3	4.76%
Perforated Colon	1	1.59%
Bilateral Below-Knee Amputation	1	1.59%
C5/6 Lesion	1	1.59%
Fracture	4	6.35%
Perforation of the Eye	1	1.59%
Shrapnel (Leg and Arm)	1	1.59%
Above-Knee Amputation	1	1.59%
Total	**63**	

Table A-16 Complete list of injuries sustained in the Israel bombings between 2000 and 2005

Wound Type	Total Injuries	% of Total Injuries
Fractures	362	14.51%
Internal Injury	297	11.91%
Open Wound	640	25.66%
Contusion/Superficial	391	15.68%
Other (Dislocations, Sprains, Strains, Amputations, Crushes, Injuries to Blood Vessels or Nerves, or Other Unspecified Injuries)	322	12.91%
System-Wide Injury	354	14.19%
Burn	128	5.13%
Total	**2,494**	

Table A-17 Complete list of injuries sustained in the Madrid, Spain bombings

Wound Type	Total Injuries	% of Total Injuries
Fractures	188	17.06%
Amputation (Extremities)	6	0.54%
Mangled Limbs	6	0.54%
Peripheral Vascular Injury	4	0.36%
Peripheral Nerve Injury	4	0.36%
Shrapnel Wounds	211	19.15%
Burns	103	9.35%
Brain Contusion	9	0.82%
Hematoma	9	0.82%
Hemorrhage	11	1.00%
Inhalation Injury	2	0.18%
Other Head Injury	16	1.45%
Tympanic Perforation	240	21.78%
Ear Lobe Amputation	13	1.18%
Eye Injury	95	8.62%
Facial Nerve Injury	1	0.09%
Blast Lung Injury	43	3.90%
Lung Contusion	58	5.26%
Pneumothorax	31	2.81%
Hemothorax	13	1.18%
Flail Chest	2	0.18%
Spinal Cord Trauma without Spine Fracture	8	0.73%
Cardiac Tamponade	1	0.09%
Abdomen Injury	28	2.54%
Total	**1,102**	

Table A-18 Complete list of injuries sustained in the Pakistan bombings between 2007 and 2009

Wound Type	Total Injuries	% of Total Injuries
Muscular Penetrating Injuries	1,127	20.91%
Lower Limb Fractures	868	16.10%
Distal Neuro-Vascular Deficit	220	4.08%
Closed Fractures	116	2.15%
Injured Hollow and Solid Viscous	375	6.96%
Liver Laceration	147	2.73%
Spleen Laceration	103	1.91%
Small Gut Ileum Laceration	337	6.25%
Perineal Injuries	25	0.46%
Blast Lung Injury	142	2.63%
Hemothorax	368	6.83%
Pneumothorax	167	3.10%
Unilateral Penetrating Chest Trauma	287	5.32%

Bilateral Penetrating Chest Trauma	81	1.50%
Blunt Chest Trauma	60	1.11%
Head Injury	143	2.65%
Spinal Cord Damage	60	1.11%
Head Injury with Spinal Cord Damage	14	0.26%
Urogenital Trauma	91	1.69%
Subclavian and Carotid Vessel Injury	17	0.32%
Submandibular Gland with Bone Fracture	12	0.22%
Complex Facial Bone Fractures	47	0.87%
Ear Injury	428	7.94%
Eye Injury	29	0.54%
Unilateral Above-Knee Amputation	30	0.56%
Below-Knee Amputation	71	1.32%
Arm Amputation	14	0.26%
Ear Amputation	5	0.09%
Disarticulation of the Hip Joint	6	0.11%
Total	**5,390**	

A.2. Complete list of Earthquake Injuries

Table A-19 through Table A-26 lists the injury types as detailed in the case study for each earthquake.

Table A-19 Complete list of injuries sustained in the Mexico City, Mexico earthquakes

Injury Type	Total Injuries	% of Total Injuries
Multiple Traumas	129(x2)	36.49%
Simple Fractures	67	9.48%
Compound Fractures	6	0.85%
Simple Contusions	142	20.08%
Wounds with contusions	82	11.60%
Other	47	6.65%
Psychological Trauma	100	14.14%
Crush Injury	5	0.71%
Total	**707**	

Table A-20 Complete list of injuries sustained in the Hanshin-Awaji, Japan earthquake

Injury Type	Total Injuries	% of Total Injuries
Burn	45	1.27%
Crush	422	11.94%
Head Injury	61	1.73%
Thoracic Injury	84	2.38%
Abdominal Injury	86	2.43%
Fracture	1,500	42.44%
Other	1,336	37.80%
Total	**3,534**	

Table A-21 Complete list of injuries sustained in the Marmara, Turkey earthquake

Injury Type	Total Injuries	% of Total Injuries
Crush Syndrome	110	26.57%
Lower Extremity Fracture	56	13.53%
Upper Extremity Fracture	13	3.14%
Pelvic Dislocation	2	0.48%
Knee Cap Dislocation	1	0.24%
Other Extremity Injury	104	25.12%

Spinal Fracture	25	6.04%
Chest Injury	20	4.83%
Abdominal Injury	19	4.59%
Cranial Injury	18	4.35%
Pelvic Fracture	12	2.90%
Other Unspecified Injury	34	8.21%
Total	**414**	

Table A-22 Complete list of injuries sustained in the Gujarat, India earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	293	51.22%
Soft Tissue Injury (Cuts, Bruises, Contusions, and Lacerations)	119	20.80%
Crush Injury	31	5.42%
Dislocations	13	2.27%
Nerve Injury	6	1.05%
Amputations	38	6.64%
Other Health Condition than Injury	72	12.59%
Total	**572**	

Table A-23 Complete list of injuries sustained in the Kashmir, India earthquake

Injury Type	Total Injuries	% of Total Injuries
Head Injury	100	55.25%
Fractures	27	14.92%
Soft Tissue Injury	10	5.52%
Dislocation	1	0.55%
Abdominal Injury	5	2.76%
Chest Injury	3	1.66%
Vascular Injury	1	0.55%
Brachial Plexus Injury	2	1.10%
Crush Injury	2	1.10%
Multiple Trauma	15(x2)	16.57%
Total	**181**	

Table A-24 Complete list of injuries sustained in the Sichuan, China earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	349	61.01%
Compartment Syndrome	18	3.15%
Major Soft Tissue Injury	21	3.67%
Crush Injuries	40	6.99%
Crush Syndrome	19	3.32%
Amputation	10	1.75%
Hemopneumothorax	15	2.62%
Abdominal Injury	9	1.57%
Acute Renal Failure	10	1.75%
Head Injury	8	1.40%
Paraplegia Associated with Vertebral Fracture	12	2.10%
Peripheral Nerve Injury	61	10.66%
Total	**572**	

Table A-25 Complete list of injuries sustained in the Padang, Indonesia earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	51	20.08%
Dislocations	21	8.27%
Sprains	46	18.11%
Laceration, Tear, Puncture Wounds	49	19.29%

Bruise	75	29.53%
Others including Burn	12	4.72%
Total	**254**	

Table A-26 Complete list of injuries sustained in the Van, Turkey earthquake

Injury Type	Total Injuries	% of Total Injuries
Fractures	295	54.53%
Superficial Lacerations	75	13.86%
Major Soft Tissue Injury	20	3.70%
Crush Injury	46	8.50%
Compartment Syndrome	28	5.18%
Hemopneumothorax	17	3.14%
Abdominal Injury	17	3.14%
Head Injury	14	2.59%
Acute Renal Failure	22	4.07%
Amputation	7	1.29%
Total	**541**	

A.3. Method of grouping injuries to types and categories for the blast cases

Table A-28 lists all of the injury types described in the case study for each bombing case. The wound type column shows how injury type can be grouped into the categories used in the analysis, such as, head trauma, chest/lung injury, or soft tissue injury. The injuries are then categorized into one of the four categories described in the Introduction section as shown in Table A-27 and in the last column of Table A-28 (The injuries shaded gray in the table show the specific injuries categorized as primary blast injury).

Table A-27 Blast injury categories, characteristics, and types of injuries from the case studies

Category	Characteristics	Types of Injuries	Additional Notes
Primary	Results from impact of overpressure wave (shock wave) with the body.	(Blast) Lung Injury, Pulmonary Contusion, Hearing Loss, Eardrum/Tympanic Membrane Rupture, (Globe) Eye Injury, Blast abdomen injury, Perforated Viscera	Injuries of these types were assumed to be caused by the blast unless otherwise stated, such as, in the Pakistan study were abdominal injuries were caused by splinters from the blast
Secondary	Results from flying debris and bomb fragments	Lacerations/Cuts, Penetrating/Perforating Injuries, Ear Amputation	
Tertiary	Results from tumbling/displacement of a person by blast forces and subsequent impact with a fixed object	Fractures or other bone injuries, Amputations, Soft Tissue Injuries, Head Trauma/Concussion, Chest/Lung Injury, Superficial/Unspecified Injuries, Neurovascular Injury, Hemorrhage/Hematoma, Blunt Internal Injury	
Quaternary	Injuries not associated with blast wave or pressure effects. Including complications of existing conditions	Burns, Psychiatric Trauma	

Table A-28 Complete list of blast injuries by case study grouped into wound type and wound category

Blast Case	Injury Type	Total Injuries	Wound Type	Wound Category
3.1	**Primary Blast Injuries**	**96**	Primary Blast Injury	Primary
3.1	Burns	50	Burns	Quaternary
3.1	Psychiatric Trauma	772	Psychiatric Trauma	Quaternary
3.1	Lacerations/Cuts	863	Lacerations/Cuts	Secondary
3.1	Amputations	20	Amputations	Tertiary
3.1	Chest Injury	10	Chest/Lung Injury	Tertiary
3.1	Fractures/Dislocations	105	Fractures	Tertiary
3.1	Concussions	34	Head Trauma	Tertiary
3.1	Neurovascular Injury	8	Neurovascular Injury	Tertiary
3.1	Soft Tissue Injuries	38	Soft Tissue Injury	Tertiary
3.1	Abrasions	359	Superficial/Unspecified Injuries	Tertiary
3.1	Contusions/Bruises	244	Superficial/Unspecified Injuries	Tertiary
3.1	Eye Injury	12	Primary Blast Injury	Primary
3.1	Perforated Tympanic Membrane	15	Primary Blast Injury	Primary
3.1	Hearing Loss	67	Primary Blast Injury	Primary
3.1	Blast Lung	2	Primary Blast Injury	Primary
3.2	**Primary Blast Injuries**	**0**	Primary Blast Injury	Primary
3.2	Psychiatric Trauma	7	Psychiatric Trauma	Quaternary
3.2	Lacerations/Cuts	55	Lacerations/Cuts	Secondary
3.2	Fractures	3	Fractures	Tertiary
3.2	Neurovascular Injury	3	Neurovascular Injury	Tertiary
3.2	Abrasions	59	Superficial/Unspecified Injuries	Tertiary
3.2	Superficial/Minor Injuries or Wounds	24	Superficial/Unspecified Injuries	Tertiary
3.3	**Primary Blast Injuries**	**30**	Primary Blast Injury	Primary
3.3	Burns	10	Burns	Quaternary
3.3	Psychiatric Trauma	4	Psychiatric Trauma	Quaternary
3.3	Fractures	24	Fractures	Tertiary
3.3	Open Joint Injuries	2	Fractures	Tertiary
3.3	Frontal Lobe and Brain Stem Damage	1	Head Trauma	Tertiary
3.3	Concussions	1	Head Trauma	Tertiary
3.3	Soft Tissue Injuries	17	Soft Tissue Injury	Tertiary
3.3	Pulmonary Contusion	2	Primary Blast Injury	Primary
3.3	Ear Injury	22	Primary Blast Injury	Primary
3.3	Abdominal Injury	2	Primary Blast Injury	Primary
3.3	Eye Damage	4	Primary Blast Injury	Primary
3.4	**Primary Blast Injuries**	**14**	Primary Blast Injury	Primary
3.4	Burns	10	Burns	Quaternary
3.4	Fractures	7	Fractures	Tertiary
3.4	Soft Tissue Injuries	11	Soft Tissue Injury	Tertiary
3.4	Blast Lung	2	Primary Blast Injury	Primary
3.4	Eye Damage	3	Primary Blast Injury	Primary
3.4	Eardrum Rupture	9	Primary Blast Injury	Primary
3.5	**Primary Blast Injuries**	**26**	Primary Blast Injury	Primary
3.5	Burns	23	Burns	Quaternary
3.5	Fractures	13	Fractures	Tertiary
3.5	Soft Tissue Injuries	22	Soft Tissue Injury	Tertiary
3.5	Blast Lung	3	Primary Blast Injury	Primary
3.5	Eye Damage	6	Primary Blast Injury	Primary

3.5	Eardrum Rupture	17	Primary Blast Injury	Primary
3.6	**Primary Blast Injuries**	**93**	Primary Blast Injury	Primary
3.6	Burn	6	Burns	Quaternary
3.6	Psychiatric Trauma	70	Psychiatric Trauma	Quaternary
3.6	Penetrating Abdomen Injury	8	Penetrating/Perforating Injury	Secondary
3.6	Penetrating Chest Injury	4	Penetrating/Perforating Injury	Secondary
3.6	Perforating Eye Injury	16	Penetrating/Perforating Injury	Secondary
3.6	Amputations	12	Amputations	Tertiary
3.6	Fractures	127	Fractures	Tertiary
3.6	Head Injury	13	Head Trauma	Tertiary
3.6	Neurovascular Injury	4	Neurovascular Injury	Tertiary
3.6	Abrasions	199	Superficial/Unspecified Injuries	Tertiary
3.6	Superficial/Minor Injuries or Wounds	188	Superficial/Unspecified Injuries	Tertiary
3.6	Ear Injury	93	Primary Blast Injury	Primary
3.7	**Primary Blast Injuries**	**33**	Primary Blast Injury	Primary
3.7	Burns	28	Burns	Quaternary
3.7	Lacerations/Cuts	15	Lacerations/Cuts	Secondary
3.7	Amputations	3	Amputations	Tertiary
3.7	Chest Wall Injury	11	Chest/Lung Injury	Tertiary
3.7	Thoracic Injury	4	Chest/Lung Injury	Tertiary
3.7	Fractures	65	Fractures	Tertiary
3.7	Brain Contusion	6	Head Trauma	Tertiary
3.7	Concussions	27	Head Trauma	Tertiary
3.7	Subcutaneous Emphysema	1	Superficial/Unspecified Injuries	Tertiary
3.7	Superficial/Minor Injuries or Wounds	57	Superficial/Unspecified Injuries	Tertiary
3.7	Abdominal Injury	7	Primary Blast Injury	Primary
3.7	Lung Contusion	4	Primary Blast Injury	Primary
3.7	Ear Injury	15	Primary Blast Injury	Primary
3.7	Eye Injury	7	Primary Blast Injury	Primary
3.8	**Primary Blast Injuries**	**81**	Primary Blast Injury	Primary
3.8	Burns	100	Burns	Quaternary
3.8	Pneumomediastinum	1	Chest/Lung Injury	Quaternary
3.8	Lacerations/Cuts	139	Lacerations/Cuts	Secondary
3.8	Other Skin Lesions	56	Lacerations/Cuts	Secondary
3.8	Eye Lesions	12	Penetrating/Perforating Injury	Secondary
3.8	Amputations	6	Amputations	Tertiary
3.8	Thoracic Injury	1	Chest/Lung Injury	Tertiary
3.8	Fractures	57	Fractures	Tertiary
3.8	Head Trauma	8	Head Trauma	Tertiary
3.8	Ear Blast Lesion	39	Primary Blast Injury	Primary
3.8	Perforated Eardrum	27	Primary Blast Injury	Primary
3.8	Lung Blast Injury	6	Primary Blast Injury	Primary
3.8	Pulmonary Contusion	1	Primary Blast Injury	Primary
3.8	Abdominal Injury	8	Primary Blast Injury	Primary
3.9	**Primary Blast Injuries**	**43**	Primary Blast Injury	Primary
3.9	Burns	16	Burns	Quaternary
3.9	Lacerations/Cuts	11	Lacerations/Cuts	Secondary
3.9	Orthopedic Related Injury	8	Fractures	Tertiary
3.9	Abrasions	12	Superficial/Unspecified Injuries	Tertiary
3.9	Superficial/Minor Injuries or Wounds	12	Superficial/Unspecified Injuries	Tertiary
3.9	Severe Multiple Trauma	3	Unspecified Severe Trauma	Tertiary
3.9	Eye Injury	1	Primary Blast Injury	Primary
3.9	Perforated Tympanic Membrane	42	Primary Blast Injury	Primary

3.10	**Primary Blast Injuries**	**44**	Primary Blast Injury	Primary
3.10	Burns	5	Burns	Quaternary
3.10	Lacerations/Cuts	20	Lacerations/Cuts	Secondary
3.10	Amputations	1	Amputations	Tertiary
3.10	Flail Chest	3	Chest/Lung Injury	Tertiary
3.10	Thoracic Injury	4	Chest/Lung Injury	Tertiary
3.10	Fractures	10	Fractures	Tertiary
3.10	Head Trauma	4	Head Trauma	Tertiary
3.10	Peritoneal-Signs	2	Unspecified/Other Internal Injury	Tertiary
3.10	Myocardial Contusion	2	Unspecified/Other Internal Injury	Tertiary
3.10	Perforated Eardrum	22	Primary Blast Injury	Primary
3.10	Blast Lung	11	Primary Blast Injury	Primary
3.10	Abdominal Injury	4	Primary Blast Injury	Primary
3.10	Perforated Ileum	1	Primary Blast Injury	Primary
3.10	Perforated Colon	1	Primary Blast Injury	Primary
3.10	Eye Injury	5	Primary Blast Injury	Primary
3.11	**Primary Blast Injuries**	**4**	Primary Blast Injury	Primary
3.11	Perforated Rectum	1	Penetrating/Perforating Injury	Secondary
3.11	Amputations	2	Amputations	Tertiary
3.11	Fractures/Defects	18	Fractures	Tertiary
3.11	Neurovascular Injury	7	Neurovascular Injury	Tertiary
3.11	Soft Tissue Injuries	32	Soft Tissue Injury	Tertiary
3.11	Hearing Loss	1	Primary Blast Injury	Primary
3.11	Perforated Abdominal Viscera	2	Primary Blast Injury	Primary
3.11	Perforated Small Bowel	1	Primary Blast Injury	Primary
3.12	**Primary Blast Injuries**	**272**	Primary Blast Injury	Primary
3.12	Burns	9	Burns	Quaternary
3.12	Acute Respiratory Distress	4	Chest/Lung Injury	Quaternary
3.12	Lacerations/Cuts	5	Lacerations/Cuts	Secondary
3.12	Amputations	1	Amputations	Tertiary
3.12	Spinal Cord Injury	1	Back/Spinal Cord Injury	Tertiary
3.12	Thoracic Injury	6	Chest/Lung Injury	Tertiary
3.12	Fractures	96	Fractures	Tertiary
3.12	Head Trauma	80	Head Trauma	Tertiary
3.12	Subdural Hematoma	2	Hemorrhage/Hematoma	Tertiary
3.12	Soft Tissue Injuries	1,409	Soft Tissue Injury	Tertiary
3.12	Severed Nerves, Tendons, or Ligaments	8	Soft Tissue Injury	Tertiary
3.12	Partial Bowel Transection	1	Unspecified/Other Internal Injury	Tertiary
3.12	Ruptured Kidney	1	Unspecified/Other Internal Injury	Tertiary
3.12	Eye Injury	59	Primary Blast Injury	Primary
3.12	Ear Injury	210	Primary Blast Injury	Primary
3.12	Lung Contusion	3	Primary Blast Injury	Primary
3.13	**Primary Blast Injuries**	**27**	Primary Blast Injury	Primary
3.13	Lacerations/Cuts	11	Lacerations/Cuts	Secondary
3.13	Partial Ear Amputation/Avulsion	2	Other Eye/Ear Injury	Secondary
3.13	Foreign Body	195	Penetrating/Perforating Injury	Secondary
3.13	Thoracic Injury	1	Chest/Lung Injury	Tertiary
3.13	Fracture/Dislocation	23	Fractures	Tertiary
3.13	Diffuse Axonal Injury	1	Head Trauma	Tertiary
3.13	Concussions	23	Head Trauma	Tertiary
3.13	Kidney Hematoma and Contusion	1	Hemorrhage/Hematoma	Tertiary
3.13	Liver Hematoma and Contusion	1	Hemorrhage/Hematoma	Tertiary
3.13	Subdural Hematoma	1	Hemorrhage/Hematoma	Tertiary

3.13	Neurovascular Injury	8	Neurovascular Injury	Tertiary
3.13	Soft Tissue Injuries	434	Soft Tissue Injury	Tertiary
3.13	Severed Tendons or Ligaments	17	Soft Tissue Injury	Tertiary
3.13	Eye Injury	27	Primary Blast Injury	Primary
3.14	**Primary Blast Injuries**	**125**	Primary Blast Injury	Primary
3.14	Burns	68	Burns	Quaternary
3.14	Psychiatric Trauma	59	Psychiatric Trauma	Quaternary
3.14	Moderate Penetrating Wound	29	Penetrating/Perforating Injury	Secondary
3.14	Amputations	24	Amputations	Tertiary
3.14	Minor Penetrating Wound or Simple Fracture	19	Superficial/Unspecified Injuries	Tertiary
3.14	Ruptured Spleen	6	Unspecified/Other Internal Injury	Tertiary
3.14	Blast Ear Injury	79	Primary Blast Injury	Primary
3.14	Blast Lung	43	Primary Blast Injury	Primary
3.14	Blast Abdomen (Intestine)	2	Primary Blast Injury	Primary
3.14	Blast Abdomen (Pneumoperitoneum)	1	Primary Blast Injury	Primary
3.15	**Primary Blast Injuries**	**1**	Primary Blast Injury	Primary
3.15	Burns	3	Burns	Quaternary
3.15	Perforation of the Eye	1	Penetrating/Perforating Injury	Secondary
3.15	Penetrating Injury	1	Penetrating/Perforating Injury	Secondary
3.15	Amputations	2	Amputations	Tertiary
3.15	Spinal Cord Injury	1	Back/Spinal Cord Injury	Tertiary
3.15	Fracture	4	Fractures	Tertiary
3.15	Superficial/Minor Injuries or Wounds	50	Superficial/Unspecified Injuries	Tertiary
3.15	Perforated Colon	1	Primary Blast Injury	Primary
3.16	**Primary Blast Injuries**	**0**	Primary Blast Injury	Primary
3.16	Burns	128	Burns	Quaternary
3.16	Open Wound	640	Penetrating/Perforating Injury	Secondary
3.16	Fractures	362	Fractures	Tertiary
3.16	Dislocations, Sprains, Strains, Amputations, Crushes, Injuries to Blood Vessels or Nerves, or Other Unspecified Injuries	322	Soft Tissue Injury	Tertiary
3.16	Contusions/Bruises	391	Superficial/Unspecified Injuries	Tertiary
3.16	System-Wide Injury	354	Unspecified Severe Trauma	Tertiary
3.16	Internal Injury	297	Unspecified/Other Internal Injury	Tertiary
3.17	**Primary Blast Injuries**	**464**	Primary Blast Injury	Primary
3.17	Burns	103	Burns	Quaternary
3.17	Inhalation Injury	2	Chest/Lung Injury	Quaternary
3.17	Ear Lobe Amputation	13	Other Eye/Ear Injury	Secondary
3.17	Penetrating Injury	211	Penetrating/Perforating Injury	Secondary
3.17	Amputations	6	Amputations	Tertiary
3.17	Spinal Cord Trauma without Spine Fracture	8	Back/Spinal Cord Injury	Tertiary
3.17	Thoracic Injury	44	Chest/Lung Injury	Tertiary
3.17	Flail Chest	2	Chest/Lung Injury	Tertiary
3.17	Fractures/Mangled Limbs	194	Fractures	Tertiary
3.17	Brain Contusion	9	Head Trauma	Tertiary
3.17	Head Trauma	16	Head Trauma	Tertiary
3.17	Hematoma	9	Hemorrhage/Hematoma	Tertiary
3.17	Hemorrhage	11	Hemorrhage/Hematoma	Tertiary
3.17	Neurovascular Injury	9	Neurovascular Injury	Tertiary
3.17	Cardiac Tamponade	1	Unspecified/Other Internal Injury	Tertiary

3.17	Eye Injury	95	Primary Blast Injury	Primary
3.17	Blast Lung Injury	43	Primary Blast Injury	Primary
3.17	Lung Contusion	58	Primary Blast Injury	Primary
3.17	Abdominal Injury	28	Primary Blast Injury	Primary
3.17	Tympanic Perforation	240	Primary Blast Injury	Primary
3.18	**Primary Blast Injuries**	**599**	Primary Blast Injury	Primary
3.18	Ear Amputation	5	Other Eye/Ear Injury	Secondary
3.18	Muscular Penetrating Injuries	1,127	Penetrating/Perforating Injury	Secondary
3.18	Penetrating Gastrointestinal Injury	962	Penetrating/Perforating Injury	Secondary
3.18	Penetrating Chest Trauma	368	Penetrating/Perforating Injury	Secondary
3.18	Amputations	121	Amputations	Tertiary
3.18	Spinal Cord Damage	60	Back/Spinal Cord Injury	Tertiary
3.18	Thoracic Injury	535	Chest/Lung Injury	Tertiary
3.18	Blunt Chest Trauma	60	Chest/Lung Injury	Tertiary
3.18	Fractures	1,043	Fractures	Tertiary
3.18	Head Injury	143	Head Trauma	Tertiary
3.18	Head Injury with Spinal Cord Damage	14	Head Trauma	Tertiary
3.18	Neurovascular Injury	237	Neurovascular Injury	Tertiary
3.18	Perineal Injuries	25	Unspecified/Other Internal Injury	Tertiary
3.18	Urogenital Trauma	91	Unspecified/Other Internal Injury	Tertiary
3.18	Ear Injury	428	Primary Blast Injury	Primary
3.18	Eye Injury	29	Primary Blast Injury	Primary
3.18	Blast Lung Injury	142	Primary Blast Injury	Primary

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